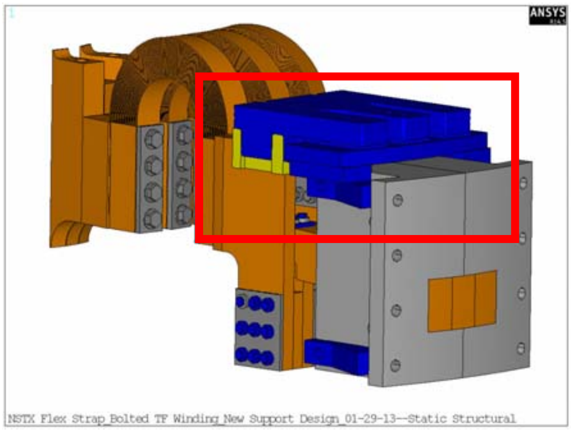
NSTX Upgrade

TF Strap Assembly Fingers

NSTXU-CALC-132-14-00

Rev 0

December 11, 2013



Prepared By:

Lawrence E. Dudek
Digitally signed by Lawrence E. Dudek
DN: cn=Lawrence E. Dudek, o=PPPL, ou=Fabrtication and Operations, email=ldudek@pppl.gov, c=US
Date: 2013.12.11 07:37:11 -05'00'

Larry Dudek, for T. Willard, M Mardenfeld, A. Brooks, Yuhu Zhai

Reviewed By:

Peter H. Titus
Digitally signed by Peter H. Titus
DN: cn=Peter H. Titus, o=PPPL, ou=MED, email=ptitus@pppl.gov, c=US
Date: 2013.12.11 07:55:59 -05'00'

P. Titus

PPPL Calculation Form

Calculation **# NSTX-CALC-132-14-00** Revision #**0** WP #**1672** (ENG-032)

Purpose of Calculation: (Define why the calculation is being performed.)

NSTX-U Upgrade TF Lead Flag Extensions Support Brackets were originally modeled as part of NSTX-U-CALC-132-06. Results indicated that parts needed to be more robust to withstand in service loads. Geometry has been iterated and a new calculation is required to document results.

References (List any source of design information including computer program titles and revision levels.)

[1] Drawing E-DC1463
[2] NSTX-CALC-132-06, T Willards TF Strap Calculation
[3] NSTX Structural Design Criteria
[4] NSTX Design Point Spreadsheet
[5] NSTXU-CALC-12-06-00 Rev 0 , Aluminum Block, P. Titus October18 2011
[6] Special Metals "Blue book" Bulletin on Inconel 718
[7] National Spherical Torus Experiment NSTX CENTER STACK UPGRADE GENERAL REQUIREMENTS DOCUMENT NSTX_CSU-RQMTS-GRD Revision 0 March 30, 2009
[8] "Mechanical, Electrical and Thermal Characterization of G10CR and G11CR Glass Cloth/Epoxy Laminates Between Room Temperature and 4 deg. K", M.B. Kasen et al , National Bureau of Standards, Boulder Colorado.

Assumptions (Identify all assumptions made as part of this calculation.)

See Ref [2]

Calculation (Calculation is either documented here or attached)

See Attached.

Conclusion (Specify whether or not the purpose of the calculation was accomplished.)

The tabs on the fingers were modeled as a continuous solid. The peak stress is where welds are proposed. As long as the welds are full penetration with a backing fillet, and it is properly aged, it will be OK. The weld should be ground smooth to remove irregularities from the weld start/stop. In the original model, the root of the tab has a radius that would be provided by the backing fillet. With these details, the weld will be consistent with Tom Willards analysis [2].

The G-10 sleeve/spacers have a peak stress that corresponds to the location of the tab peak stress. The peak stress is a combination of shear and local compression. The fabric plane of the G-10 should be oriented parallel to the end face of the sleeve/spacer.

Cognizant Engineer's printed name, signature, and date

James H. Chrzanowski

Digitally signed by James H. Chrzanowski
DN: cn=James H. Chrzanowski, o=PPPL, ou=Mech Engineering, email=jchrzano@pppl.gov, c=US
Date: 2013.12.12 09:48:23 -05'00'

I have reviewed this calculation and, to my professional satisfaction, it is properly performed and correct.

Checker's printed name, signature, and date

Peter H. Titus

Digitally signed by Peter H. Titus
DN: cn=Peter H. Titus, o=PPPL, ou=MED, email=ptitus@pppl.gov, c=US
Date: 2013.12.11 07:56:19 -05'00'

Executive Summary

Tom Willard originally modeled the TF joint assembly [2] The focus of the analysis was the TF strap that connected to the inner leg. . The calculations later included the hardware connections to the outer leg. Tom updated his modeling of the fingers and the flag extensions in Feburary 2012, and the power point slides from his Peer review are included in this calculation. The finger details which are the focus of this calculation provide support for the outer TF flag connections. The finger details were intended to be machined from a solid.

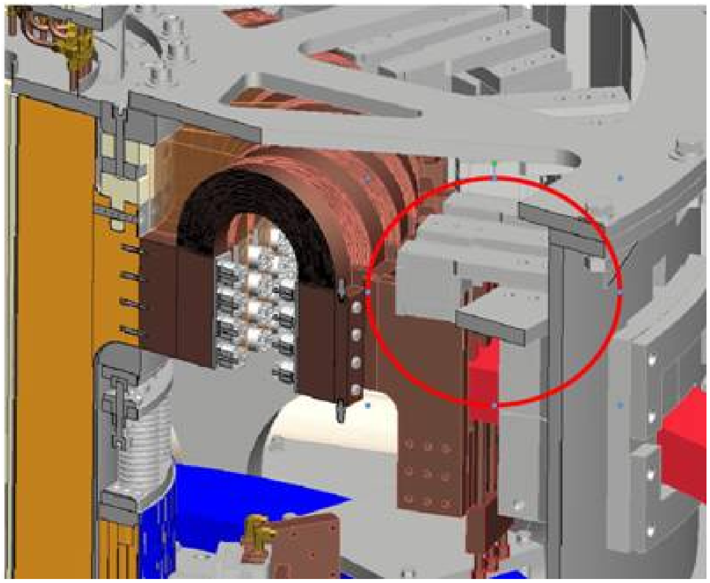


Figure 1 TF Flex Joint with Fingers Highlighted

. The finger material specified was Inconel 718. This is expensive both in terms of material and in the machining costs. M. Mardenfeld proposes to weld the finger tabs and then finish machine where needed and then do a final heat treat to restore the strength of the 718. Tom Willard left all the analysis files, and with a capable computer these could be queried and the stresses in the local areas of the fingers, where welds are prorposed, could be investigated. Art Brooks loaded the results files and provided the plots of the areas of interest.

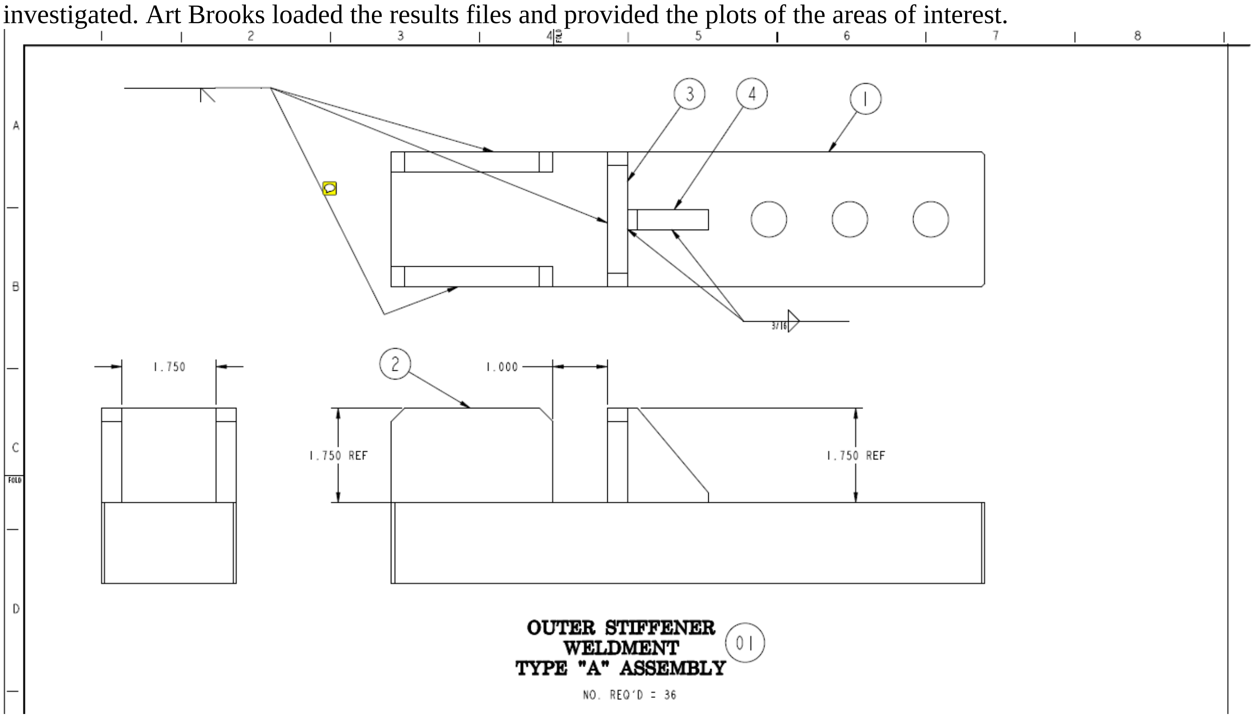


Figure 2 Type A “Finger”

. The peak stress is where welds are proposed. As long as the welds are full penetration with a backing fillet, and it is properly aged, it will be OK. The weld should be ground smooth to remove irregularities from the weld start/stop. In the original model, the root of the tab has a radius that would be provided by the backing fillet. With these details, the weld will be consistent with Tom Willards analysis [2].

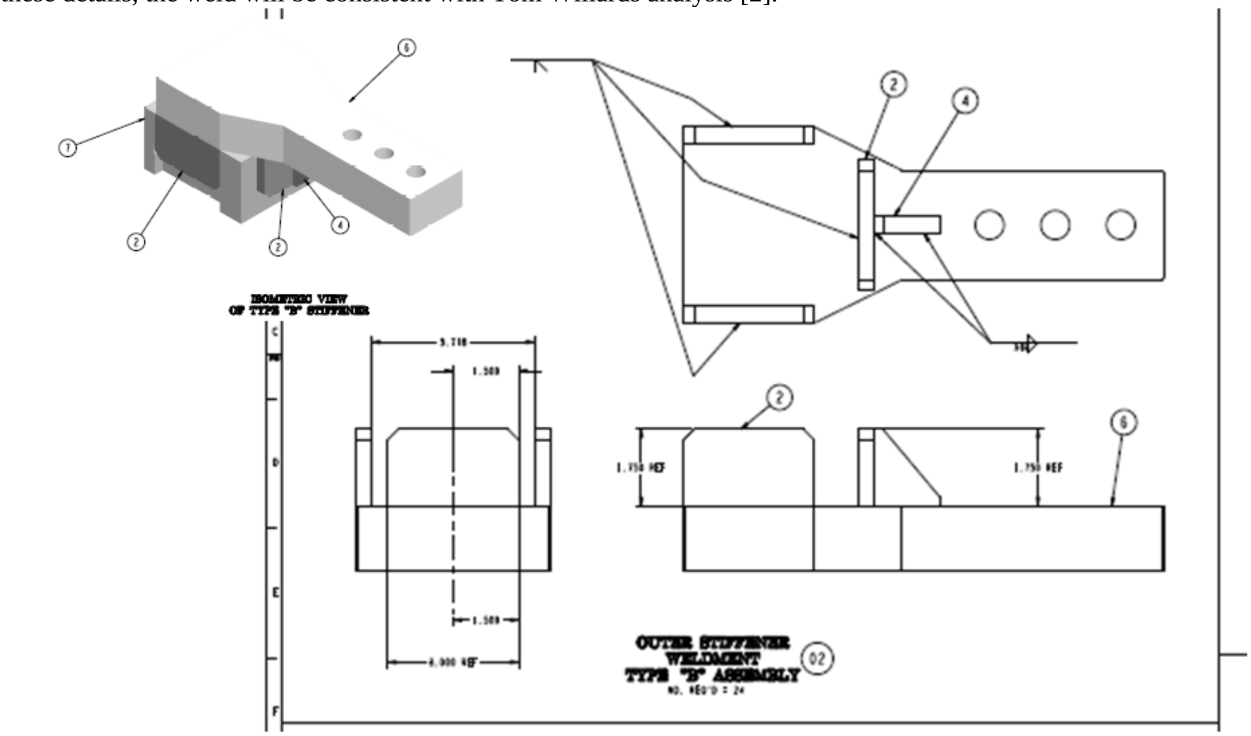


Figure 3 Type B “Finger

The bolted connection to the ring and the ring connection to the umbrella structure wall has evolves since Tom Willard built his model. Analyses of a later configuration is included in ref [5], but the specific details of the bolting and ring attachment to the aluminum block reinforcements has not been determined yet (as of Dec 2013)

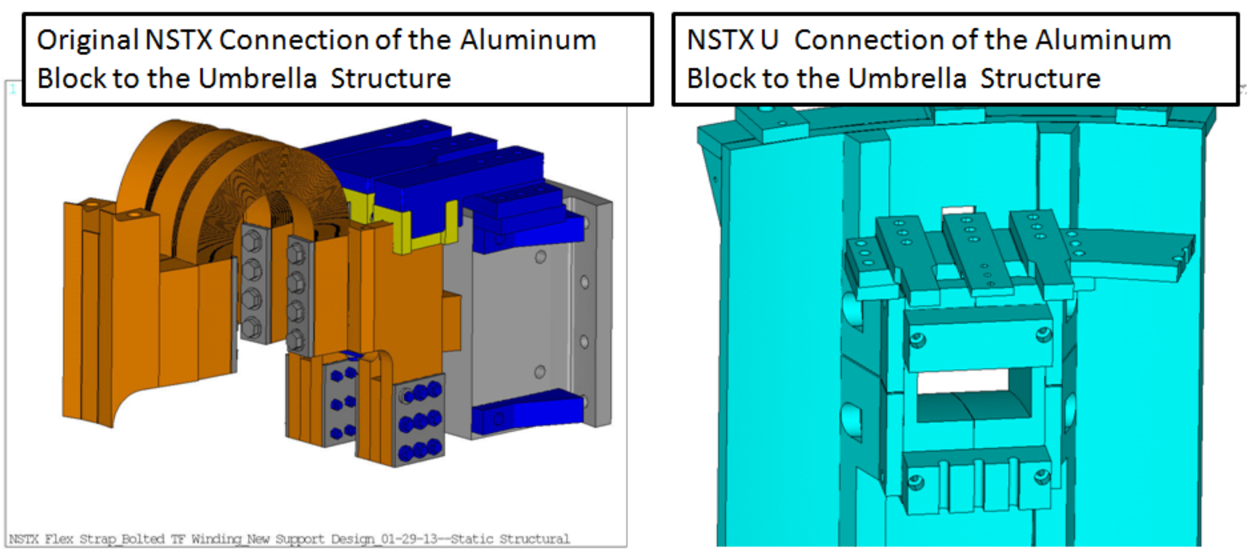


Figure 4

Art Brooks Post Process of the Finger Details

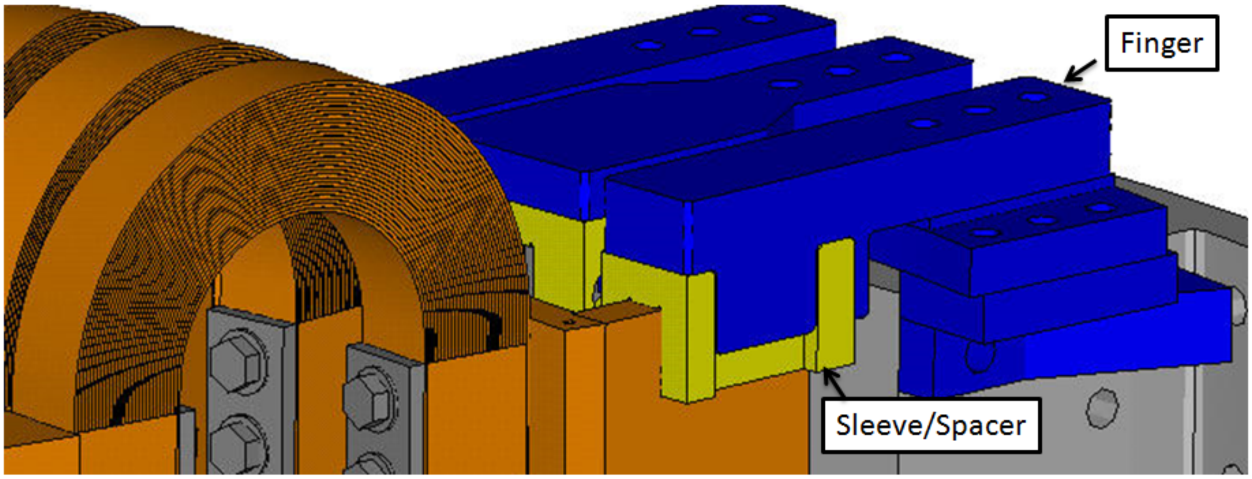


Figure 5

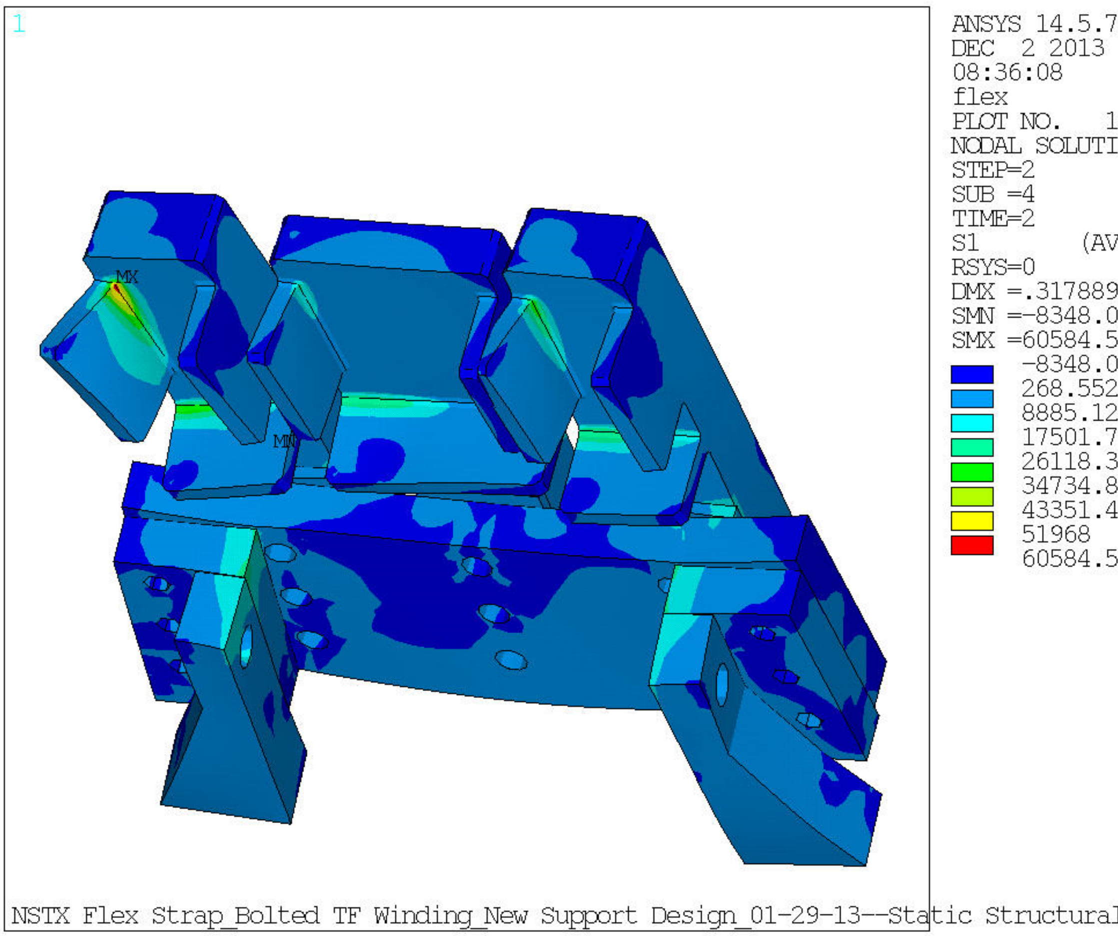


Figure 6

Weld Fatigue Properties

Weldments were found to have a room-temperature fatigue strength (10^8 cycles) of approximately 62.5 ksi (tested in R.R. Moore rotating-beam apparatus). They were made from hot-rolled , annealed (per AMS 5596) 0.500-in. plate, joined with 0.125-in.-diameter INCONEL Filler Metal 718 by the gas tungsten-arc process. Samples were aged 1325°F/8 hr, F.C. to 1150°F, hold at 1150°F for total aging time of 18 hours and tested as polished specimens. In comparable tests, alloy 718 bar had a fatigue strength (10^8 cycles) of 89.0 ksi.

Figure 7 Excerpt from Special Metals Bulletin on 718

The 60 ksi peak stress in the tab weld is acceptable based on the special metals, ref [6] indication of the endurance limit at 62.5 ksi, and the required life of, 20,000 full power stress cycles (fron the NSTX GRD) [7]

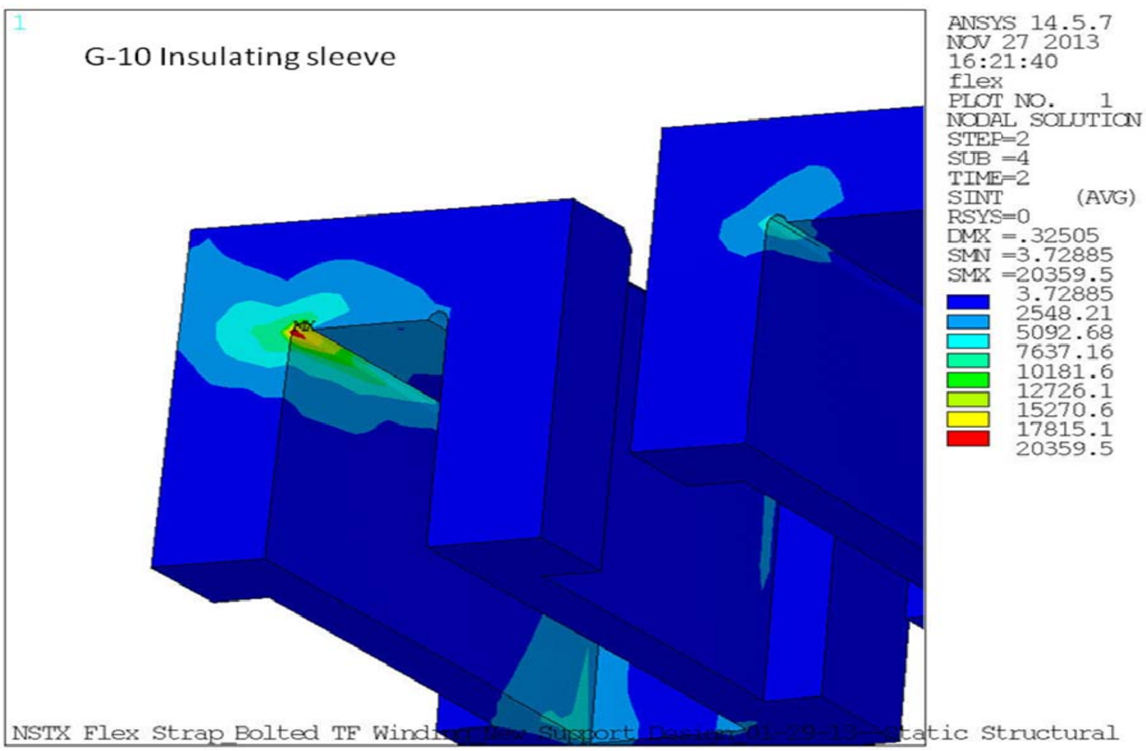


Figure 8

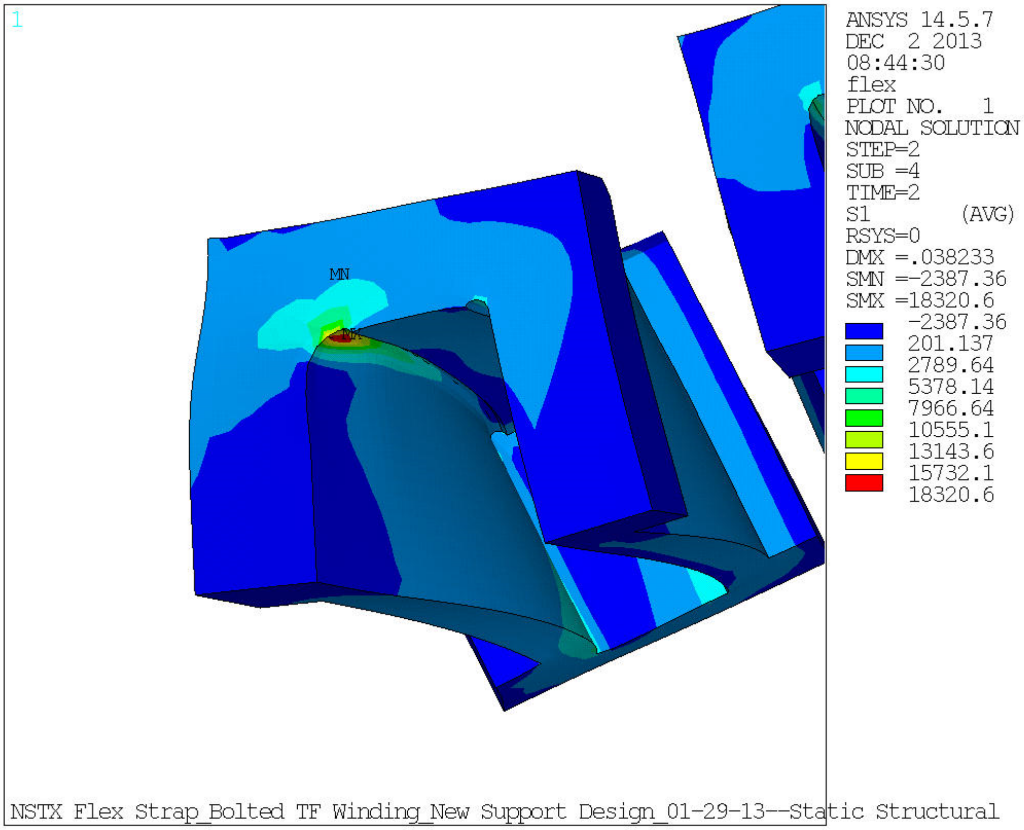


Figure 9

The stress component plots are intended to show the directional nature of the stresses on the sleeve/spacer. The plane of the reinforcement of the G-10 should be parallel to he end face in these plots.

Insulating Material Strengths

	@4	@77	@292 degK
Comp.Strength Normal to Fiber			
G-10CR	749	693	420 Mpa Ref[8]
G-11CR	776	799	461 MPa Ref[8]
Tensile Strength (Warp)			
G-10CR	862	825	415 MPa Ref[8]
G-11CR	872	827	469 MPa Ref[8]
Tensile Strength (Fill)			
G-10CR	496	459	257 MPa Ref[8]
G-11CR	553	580	329 MPa Ref[8]

The RT tensile strength in the reinforced direction is 257 MPa or 37 ksi – sufficient for the 20 ksi applied in the corner

Finger Loads Post Processing by Yuhu Zhai

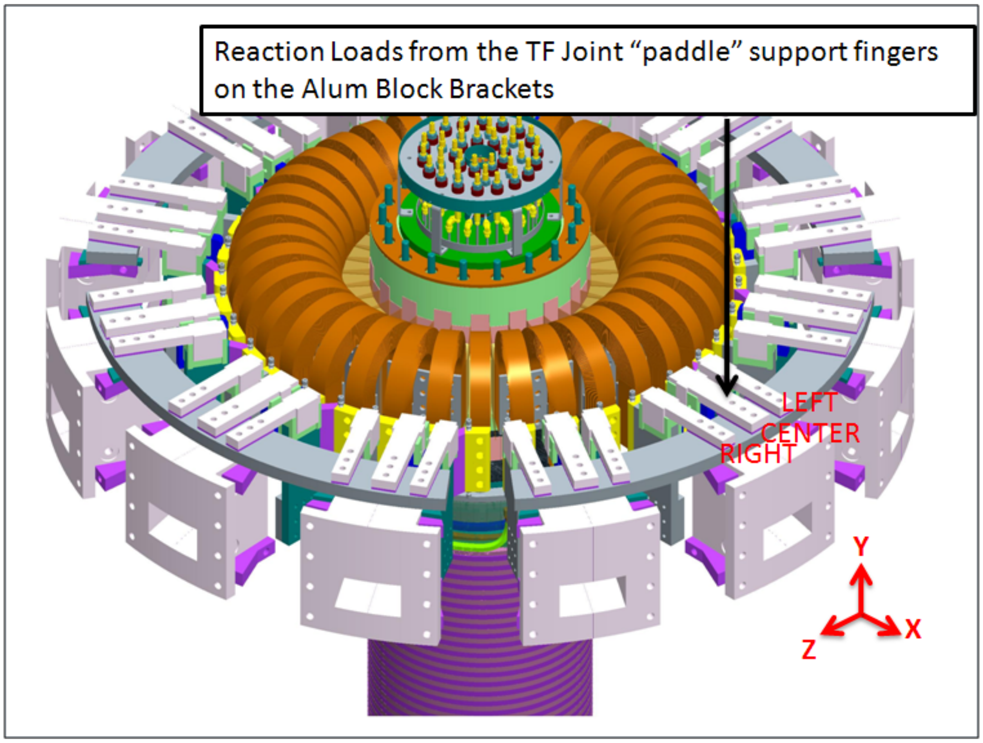


Figure 9

Hi Pete,

Mon 7/25/2011 4:21 PM

Please find attached the reaction loads at TF joint support fingers (LEFT, CENTER, RIGHT). The results are extracted via post-processing from Tom Willard Flex Strap model – with imported body temperature from transient thermal analysis and body force density from Maxwell.

Let me know if you have any questions.

Regards,
Yuhu

Reaction Forces

	Fx (kN)	Fy (kN)	Fz (kN)	Net Force (kN)
LEFT	-19.9	3.35	4.56	20.7
CENTER	-18.0	0.46	-0.46	18.0
RIGHT	-27.6	-12.6	2.42	30.4

Reaction Moments

	Tx (kNm)	Ty (kNm)	Tz (kNm)	Net Moment (kNm)
LEFT	0.03	-1.54	0.036	1.54
CENTER	0.05	0.54	0.29	0.62
RIGHT	0.14	1.2	1.78	2.15

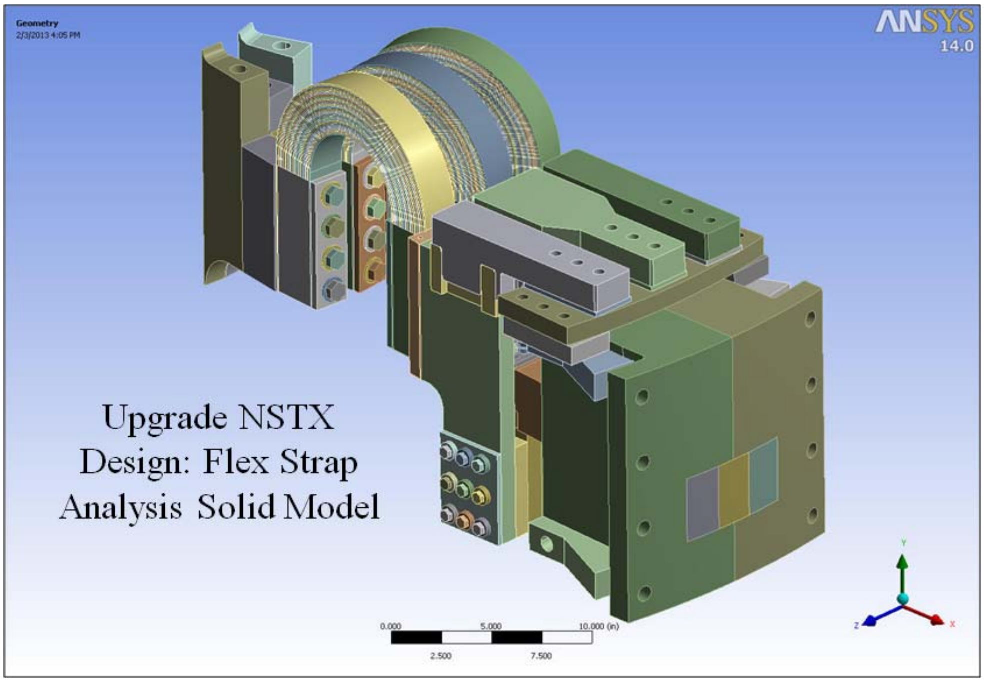
Moment is given at the center of the Flex Strap global model

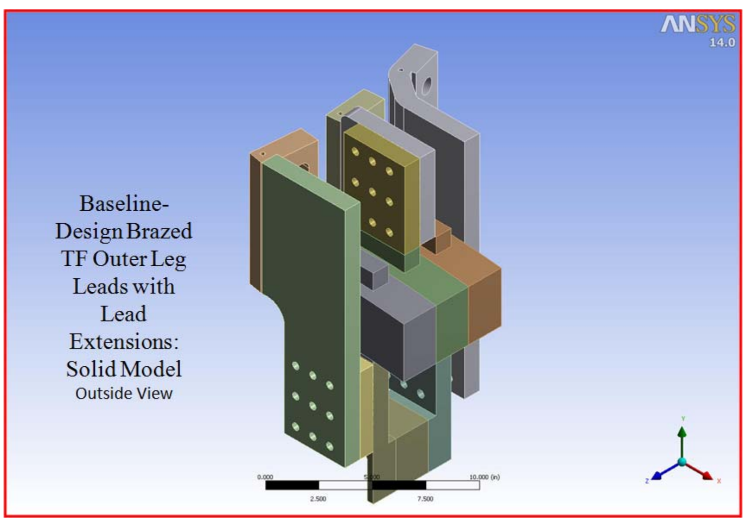
Figure 10

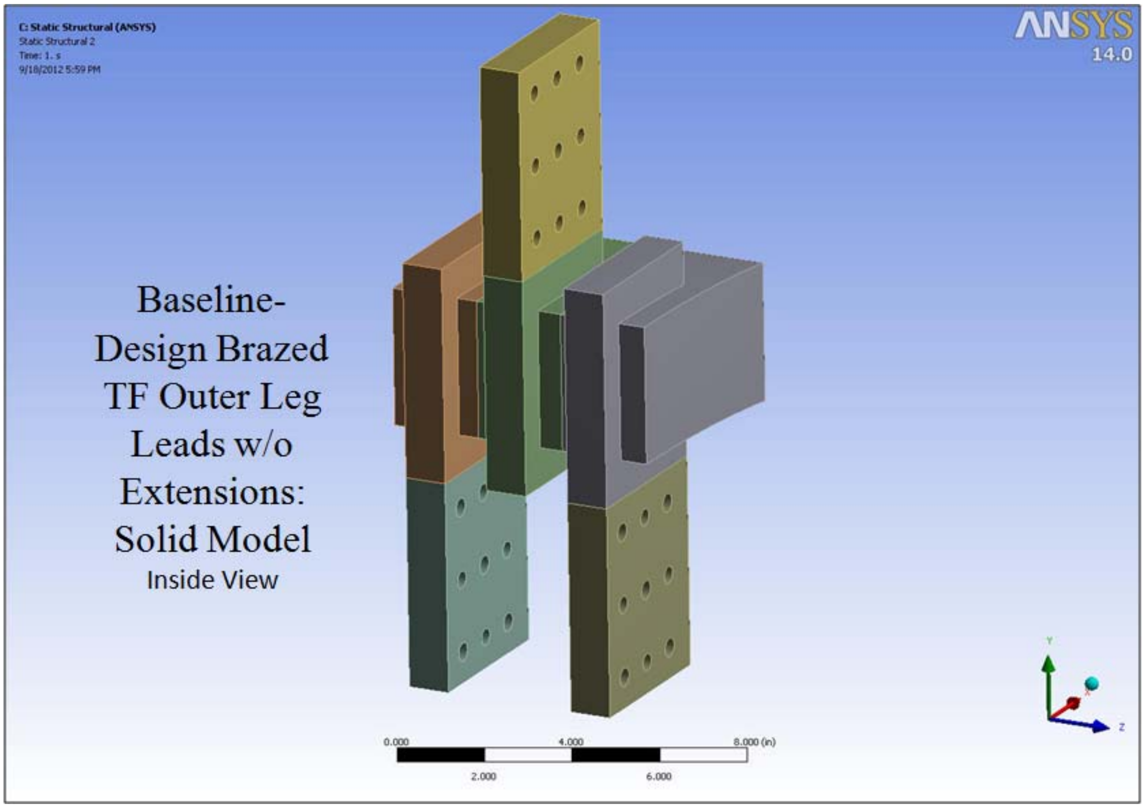
TF Outer Leg Flag-to-Lead Bolted Joint Design

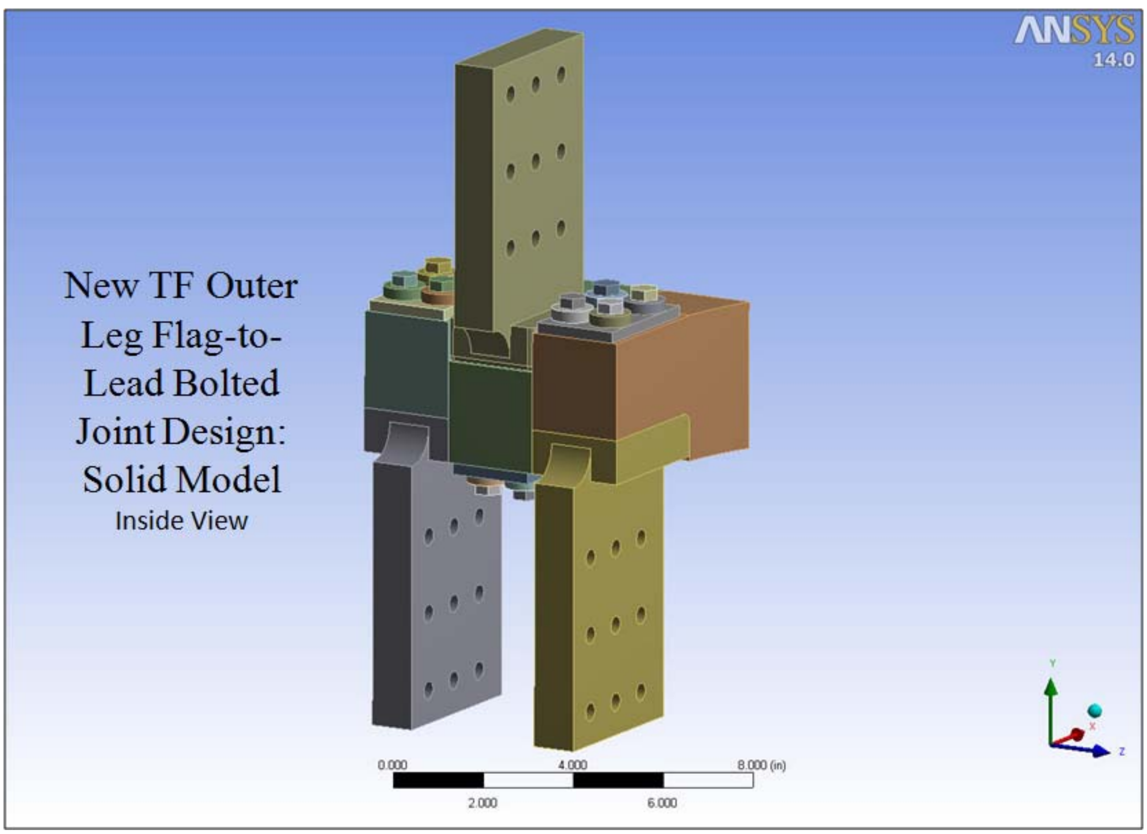
T. Willard

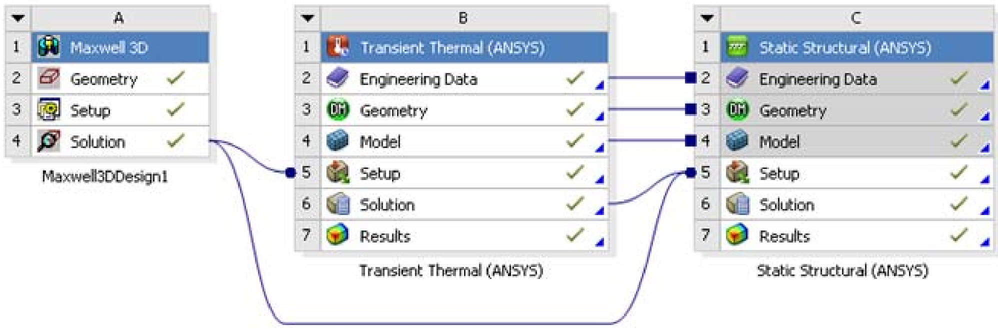
02-04-13



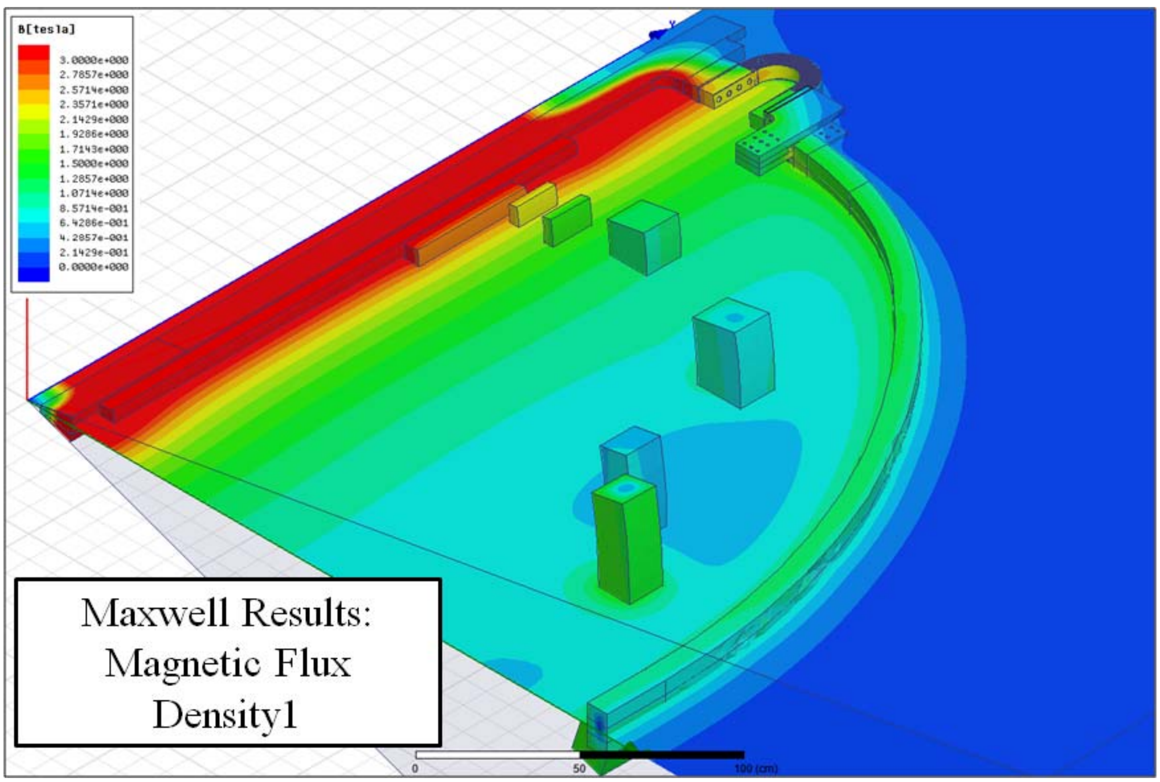


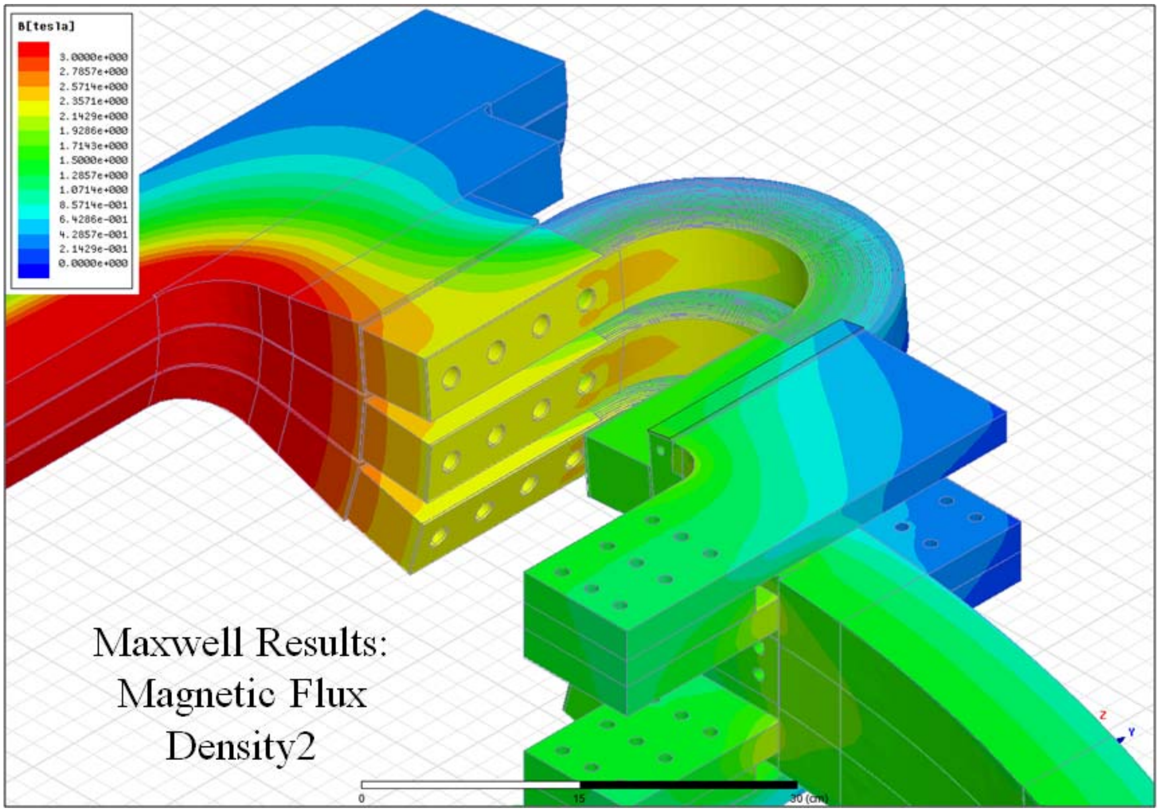

C: Static Structural (ANSYS)
Static Structural 2
Time: 1. s
9/18/2012 5:59 PM
ANSYS
14.0
Baseline-Design Brazed TF Outer Leg Leads w/o Extensions: Solid Model
Inside View
0.000
4.000
8.000 (in)
2.000
6.000
Y
Z

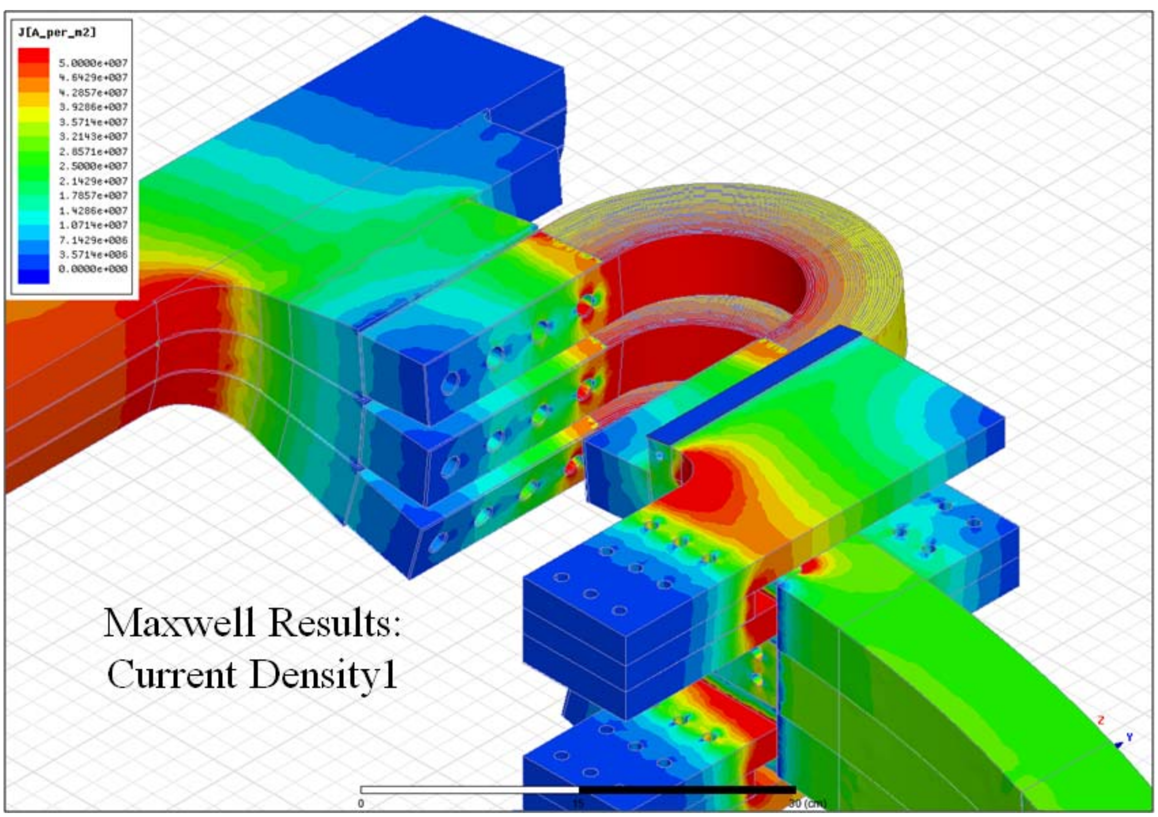

ANSYS
14.0
New TF Outer Leg Flag-to-Lead Bolted Joint Design: Solid Model
Inside View
0.000
4.000
8.000 (in)
2.000
6.000
Y
Z

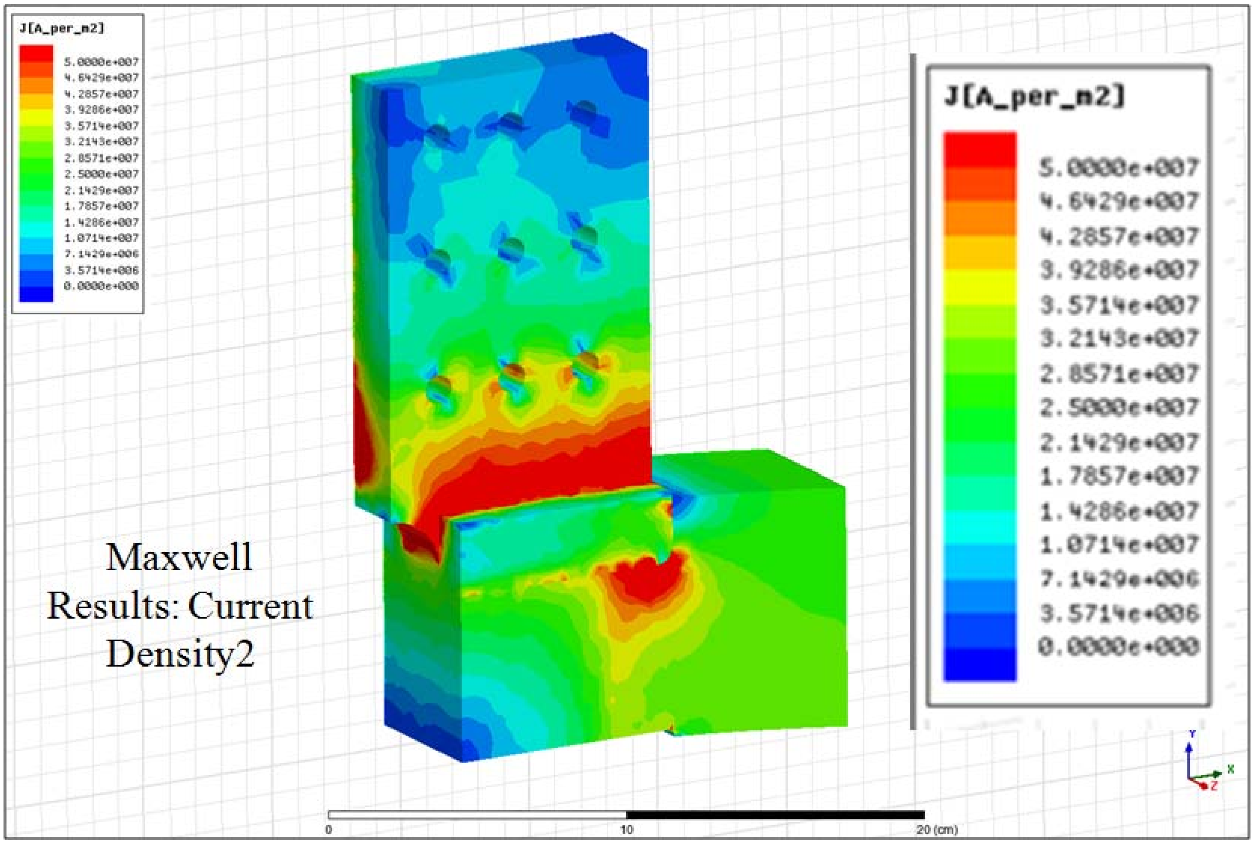


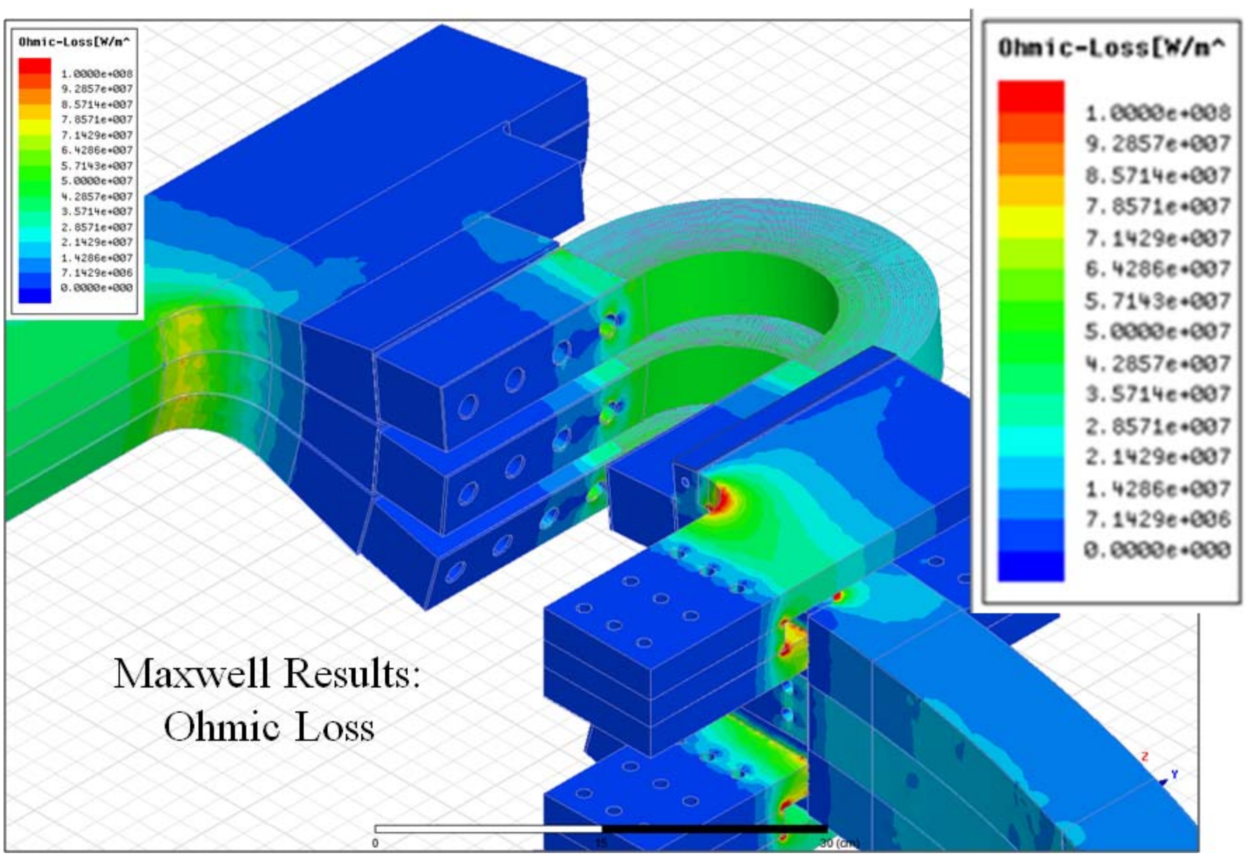
New TF Outer Leg Bolted Joint Design Analysis Project Page

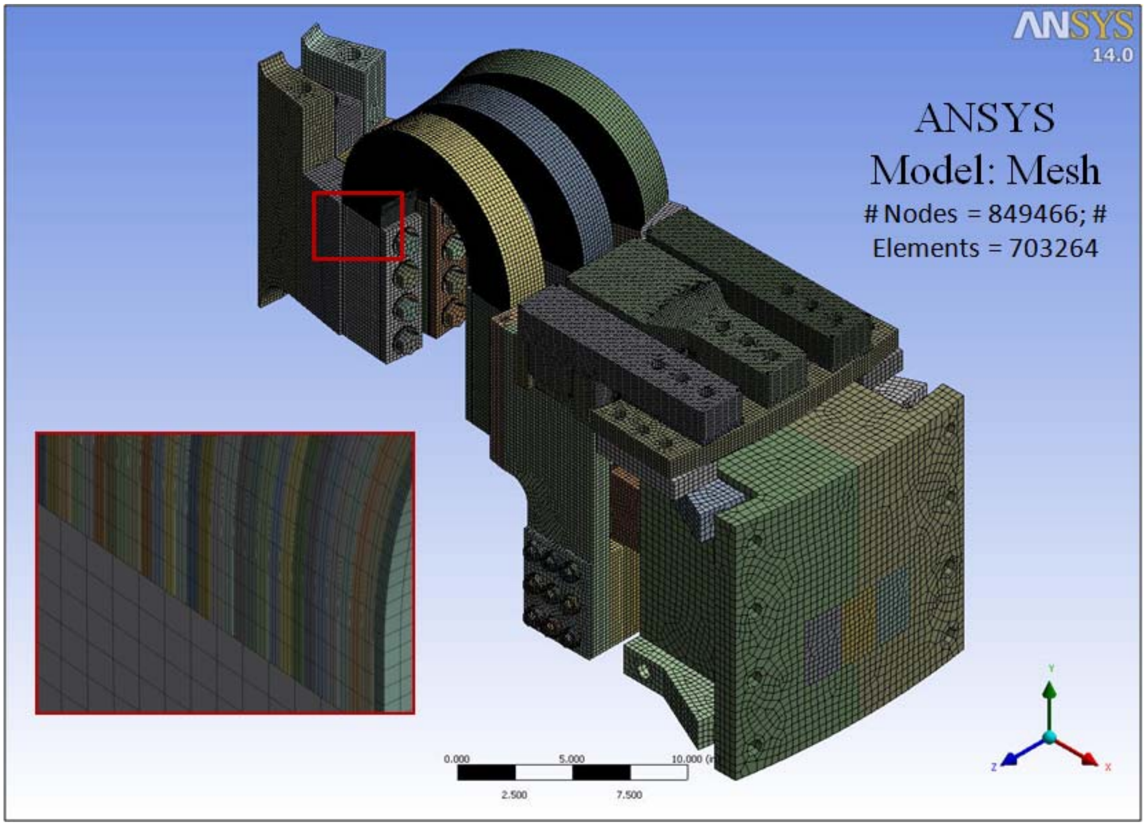


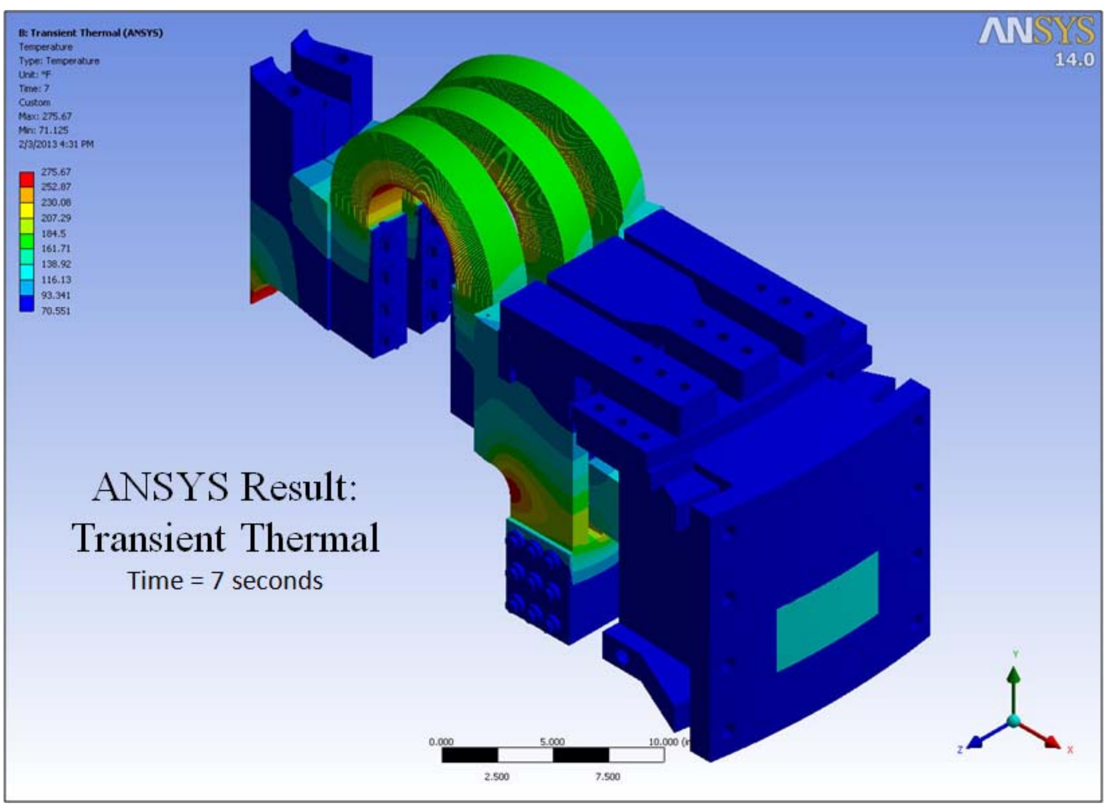

B[tesla]
3.0000e+000
2.7857e+000
2.5714e+000
2.3571e+000
2.1429e+000
1.9286e+000
1.7143e+000
1.5000e+000
1.2857e+000
1.0714e+000
8.5714e-001
6.4286e-001
4.2857e-001
2.1429e-001
0.0000e+000
Maxwell Results:
Magnetic Flux
Density2
0
15
30 (cm)

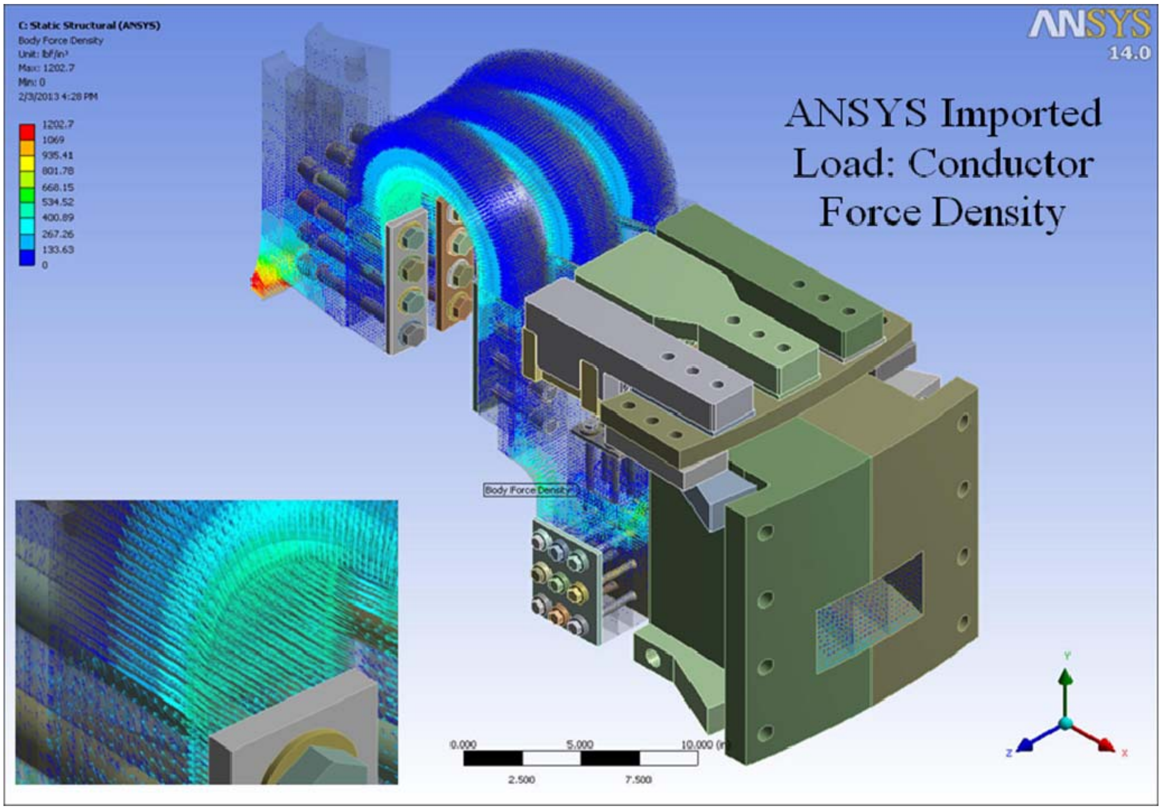

J[A_per_m2]
5.0000e+007
4.6429e+007
4.2857e+007
3.9286e+007
3.5714e+007
3.2143e+007
2.8571e+007
2.5000e+007
2.1429e+007
1.7857e+007
1.4286e+007
1.0714e+007
7.1429e+006
3.5714e+006
0.0000e+000
Maxwell Results:
Current Density1
0
15
30 (cm)

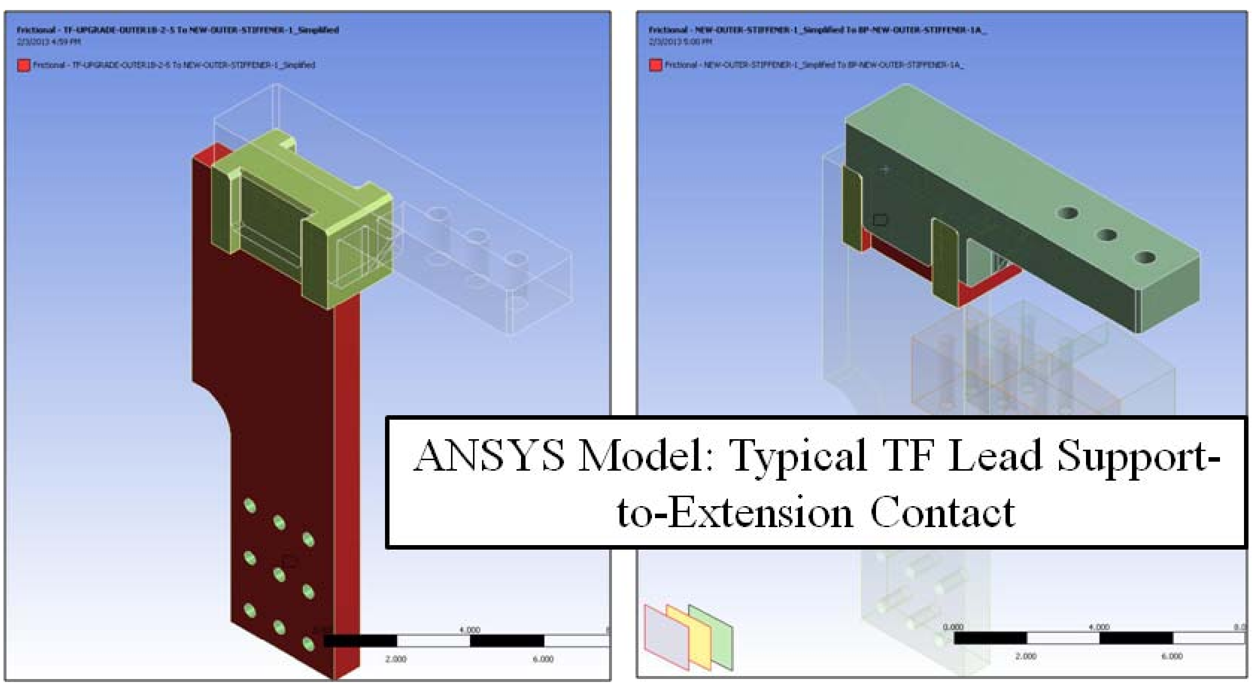

J[A_per_m2]
5.0000e+007
4.6429e+007
4.2857e+007
3.9286e+007
3.5714e+007
3.2143e+007
2.8571e+007
2.5000e+007
2.1429e+007
1.7857e+007
1.4286e+007
1.0714e+007
7.1429e+006
3.5714e+006
0.0000e+000
Maxwell Results: Current Density2
0
10
20 (cm)

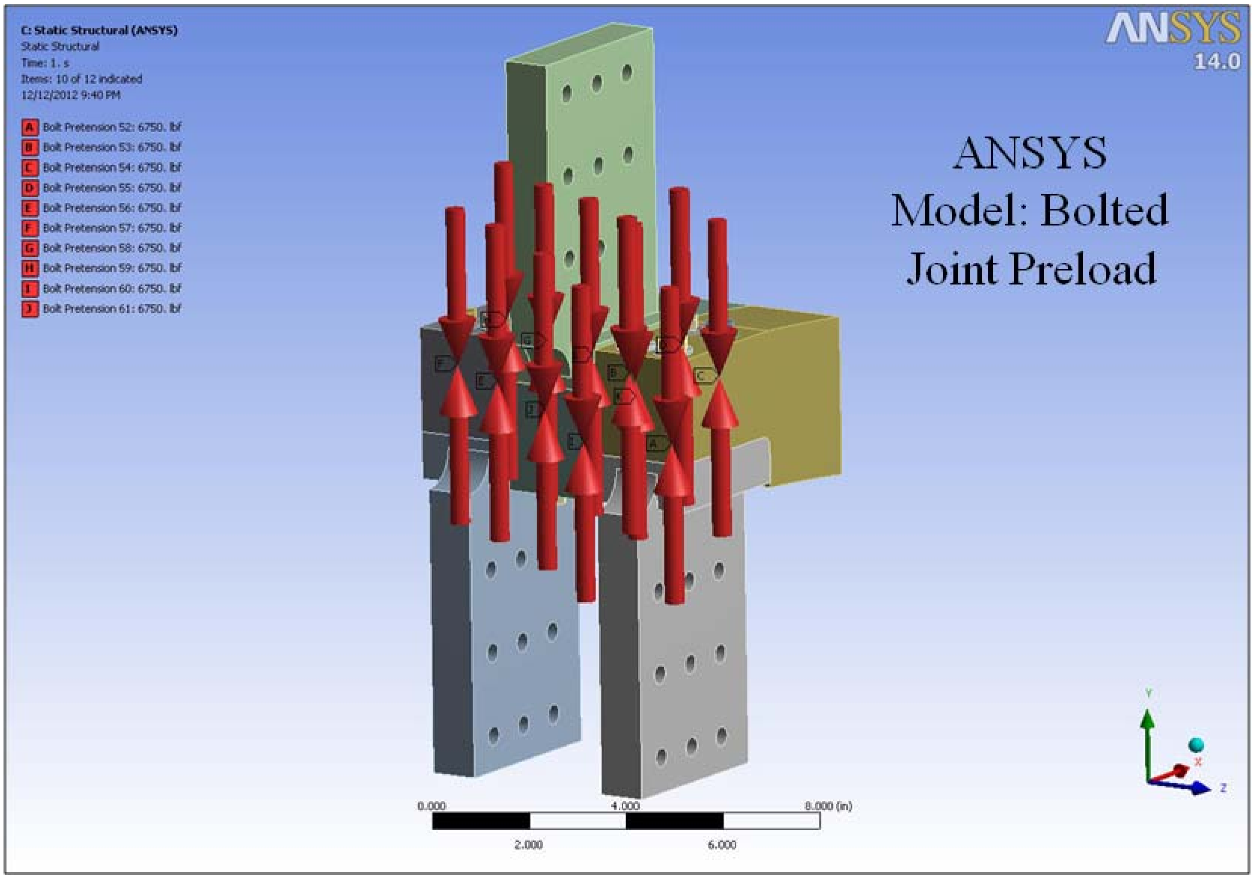

Ohmic-Loss[W/m^
1.0000e+008
9.2857e+007
8.5714e+007
7.8571e+007
7.1429e+007
6.4286e+007
5.7143e+007
5.0000e+007
4.2857e+007
3.5714e+007
2.8571e+007
2.1429e+007
1.4286e+007
7.1429e+006
0.0000e+000
Maxwell Results: Ohmic Loss
0

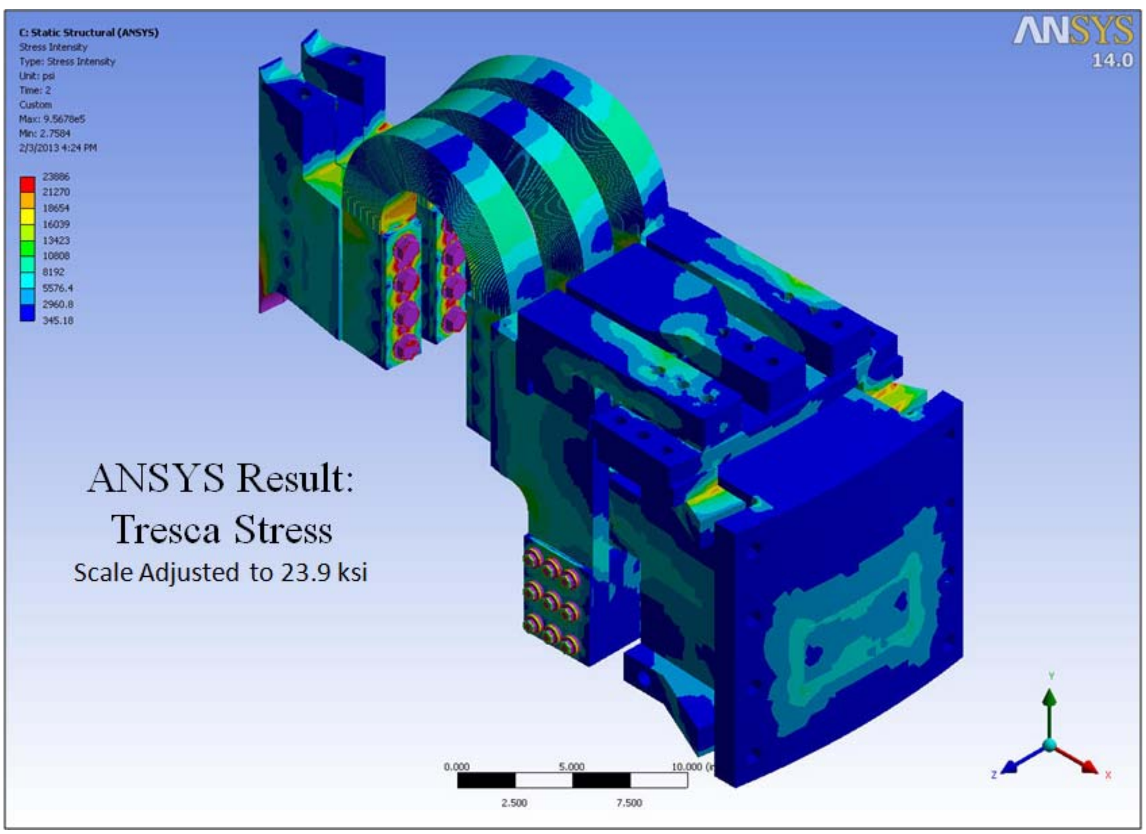

ANSYS
14.0
ANSYS
Model: Mesh
# Nodes = 849466; #
Elements = 703264
0.000
5.000
2.500
7.500
Y
Z
X

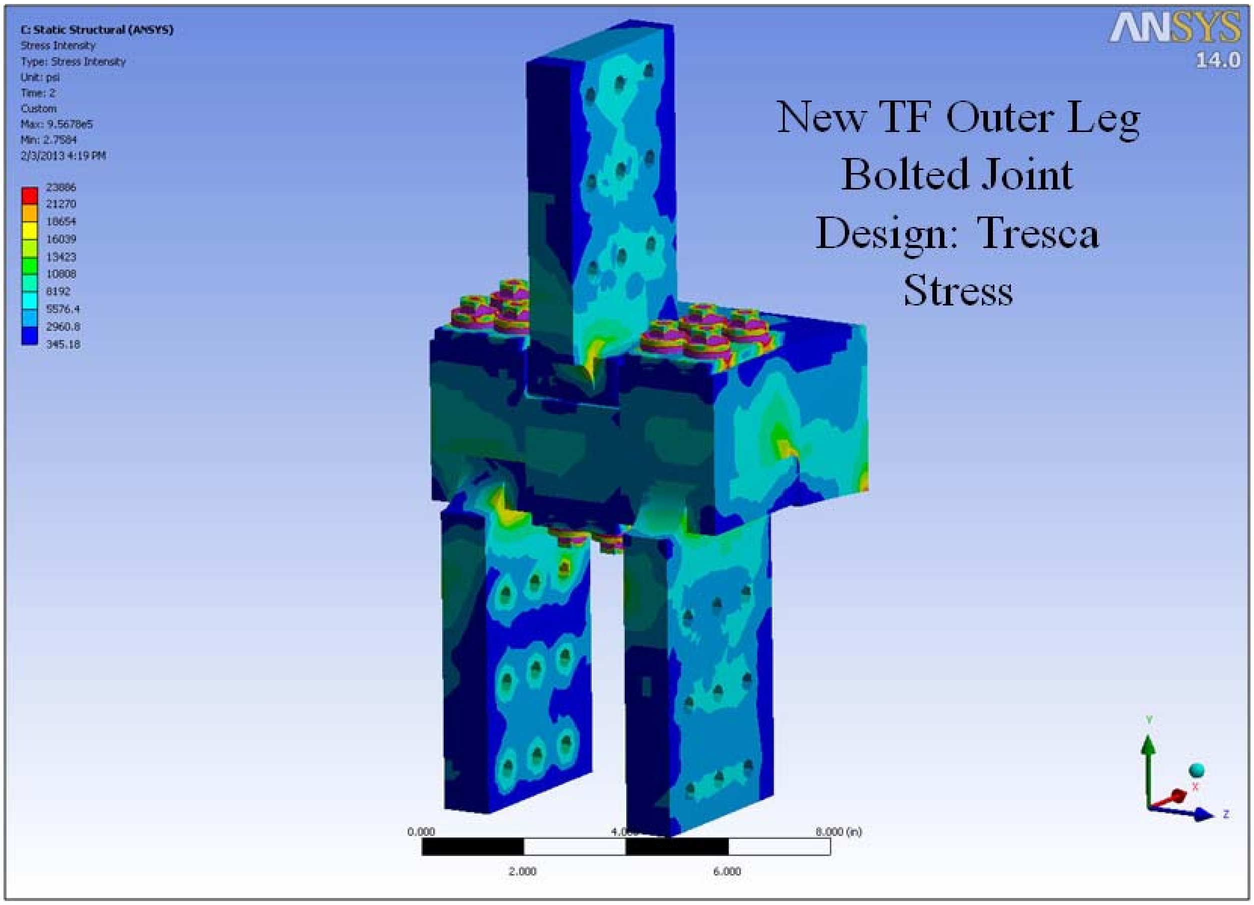

B: Transient Thermal (ANSYS)
Temperature
Type: Temperature
Unit: °F
Time: 7
Custom
Max: 275.67
Min: 71.125
2/3/2013 4:31 PM
275.67
252.87
230.08
207.29
184.5
161.71
138.92
116.13
93.341
70.551
ANSYS
14.0
ANSYS Result:
Transient Thermal
Time = 7 seconds
0.000
5.000
2.500
7.500
Y
Z
X

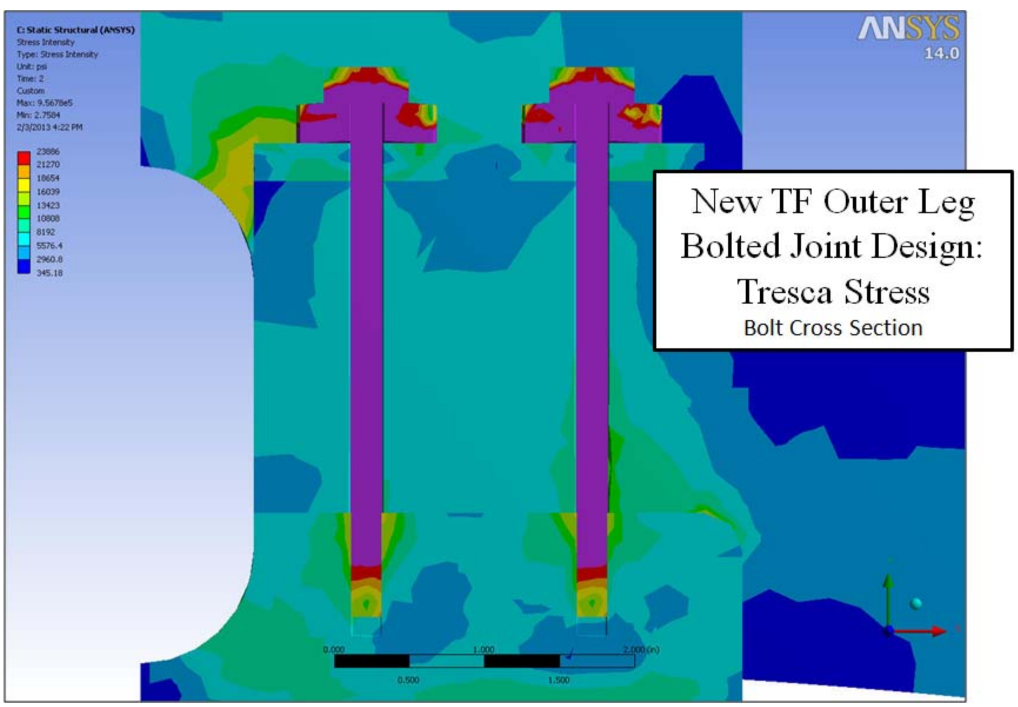

C: Static Structural (ANSYS)
Body Force Density
Max: 1202.7
Min: 0
2/3/2013 4:28 PM
ANSYS
14.0
ANSYS Imported Load: Conductor Force Density
Body Force Density


Frictional - TF-UPGRADE-OUTER1B-2-5 To NEW-OUTER-STIFFENER-1_Simplified
Frictional - NEW-OUTER-STIFFENER-1_Simplified To BP-NEW-OUTER-STIFFENER-1A_
ANSYS Model: Typical TF Lead Support-to-Extension Contact


C: Static Structural (ANSYS)
Static Structural
Time: 1. s
Items: 10 of 12 indicated
12/12/2012 9:40 PM
A Bolt Pretension 52: 6750. lbf
B Bolt Pretension 53: 6750. lbf
C Bolt Pretension 54: 6750. lbf
D Bolt Pretension 55: 6750. lbf
E Bolt Pretension 56: 6750. lbf
F Bolt Pretension 57: 6750. lbf
G Bolt Pretension 58: 6750. lbf
H Bolt Pretension 59: 6750. lbf
I Bolt Pretension 60: 6750. lbf
J Bolt Pretension 61: 6750. lbf
ANSYS 14.0
ANSYS
Model: Bolted
Joint Preload
0.000
4.000
8.000 (in)
2.000
6.000


C: Static Structural (ANSYS)
Stress Intensity
Type: Stress Intensity
Unit: psi
Time: 2
Custom
Max: 9.5678e5
Min: 2.7584
2/3/2013 4:24 PM
23886
21270
18654
16039
13423
10808
8192
5576.4
2960.8
345.18
ANSYS 14.0
ANSYS Result:
Tresca Stress
Scale Adjusted to 23.9 ksi
0.000
5.000
2.500
7.500


C: Static Structural (ANSYS)
Stress Intensity
Type: Stress Intensity
Unit: psi
Time: 2
Custom
Max: 9.5678e5
Min: 2.7584
2/3/2013 4:19 PM
23886
21270
18654
16039
13423
10808
8192
5576.4
2960.8
345.18
ANSYS
14.0
New TF Outer Leg Bolted Joint Design: Tresca Stress
0.000
8.000 (in)
2.000
6.000


C: Static Structural (ANSYS)
Stress Intensity
Type: Stress Intensity
Unit: psi
Time: 2
Custom
Max: 9.5678e5
Min: 2.7584
2/3/2013 4:22 PM
23886
21270
18654
16039
13423
10808
8192
5576.4
2960.8
345.18
ANSYS
14.0
New TF Outer Leg Bolted Joint Design: Tresca Stress
Bolt Cross Section
0.000
1.000
2.000 (in)
0.500
1.500

NIST Monograph 177

Properties of Copper and Copper Alloys at Cryogenic Temperatures

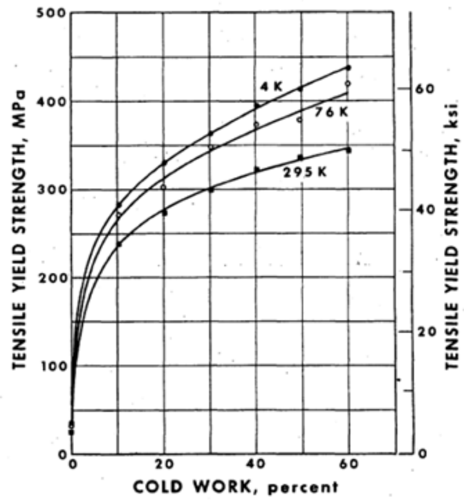
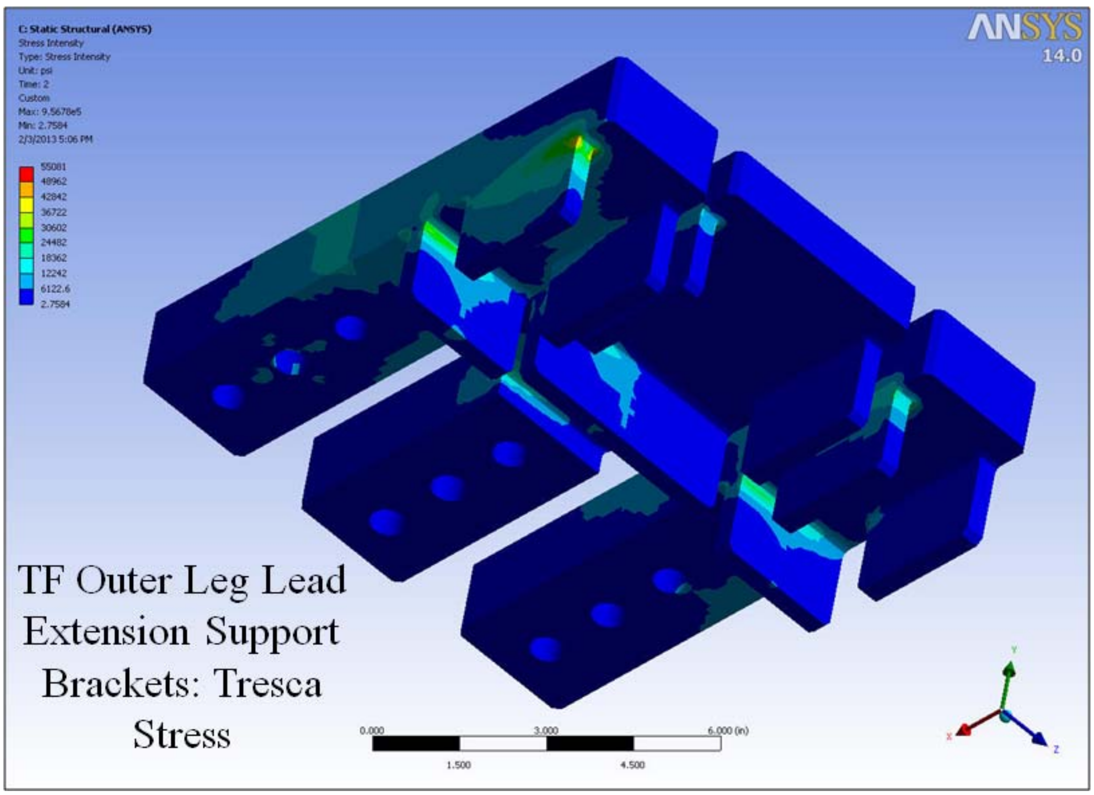


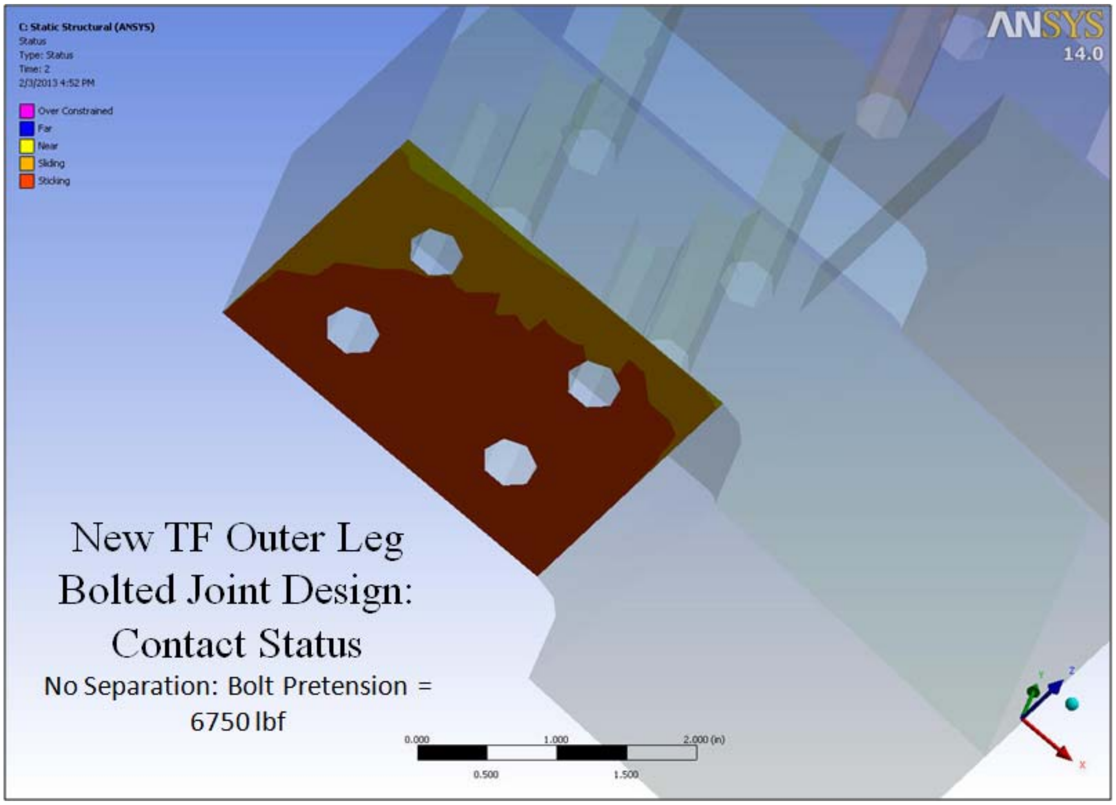
Figure 2.13. These data from Reference 2.34 indicate the increase of tensile yield strength with increased cold work or lowered temperature (C10400 plate).

TF Outer Leg C10700 Copper: Yield Strength vs % Cold Work

Min. Anneal Temp = 475 C



TF Outer Leg Lead Extension Support Brackets: Tresca Stress

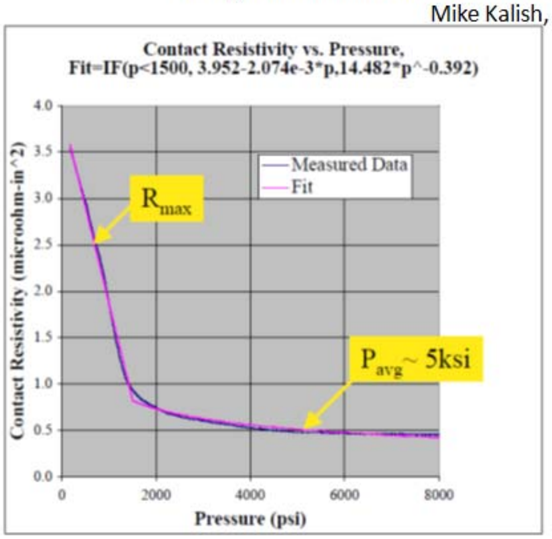


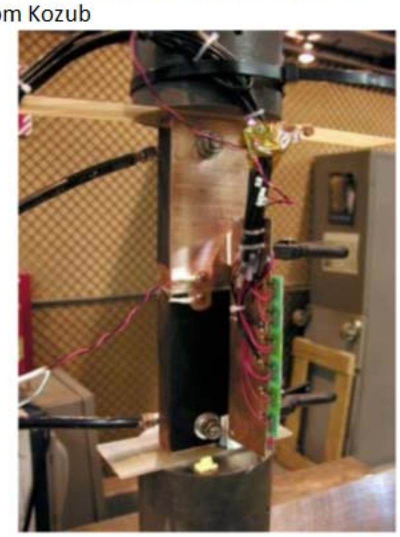
PPPL — NSTX

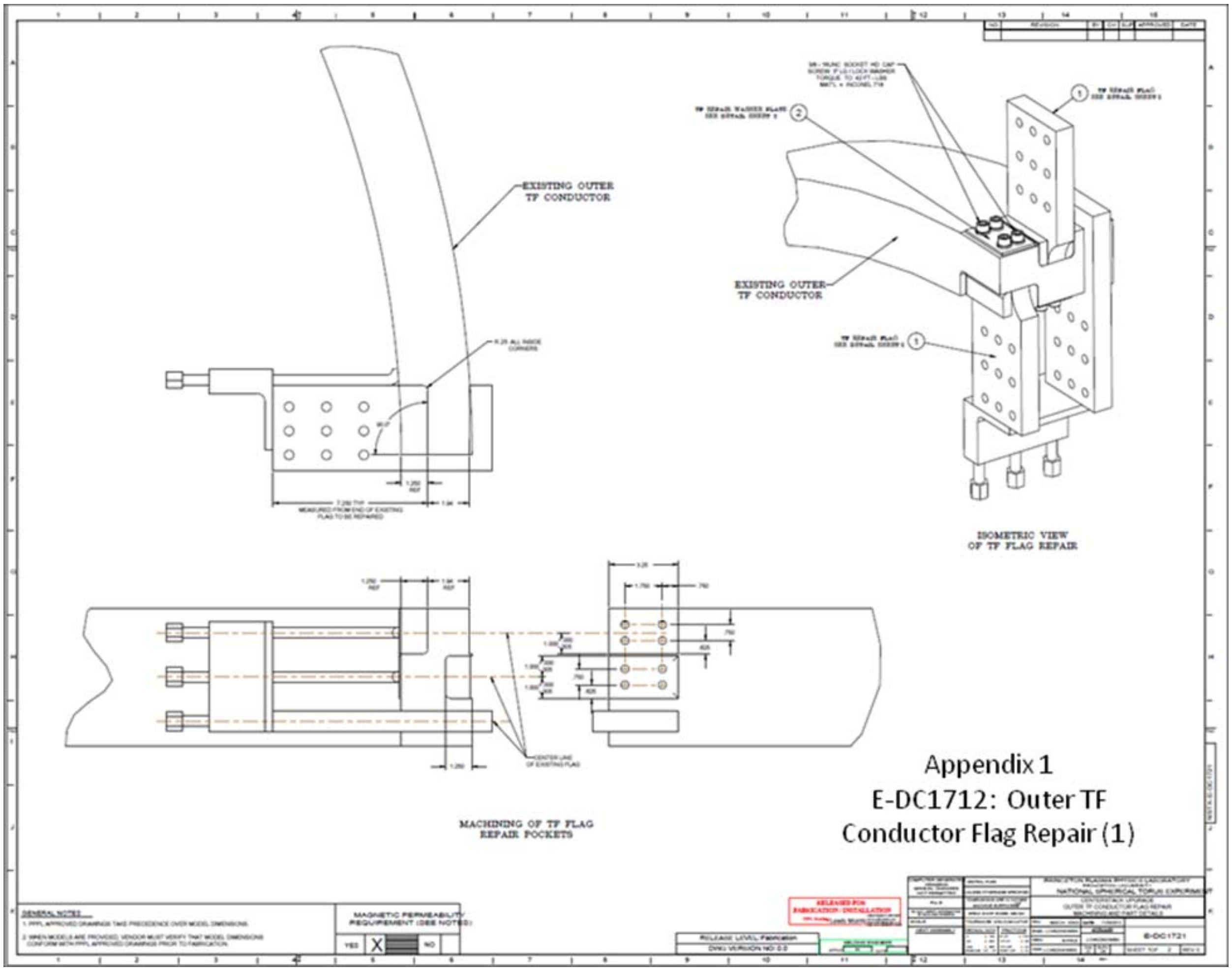
CONTACT PRESSURE & RESISTANCE

TF Flag Electrical Contact Resistance versus Contact Pressure Measurements

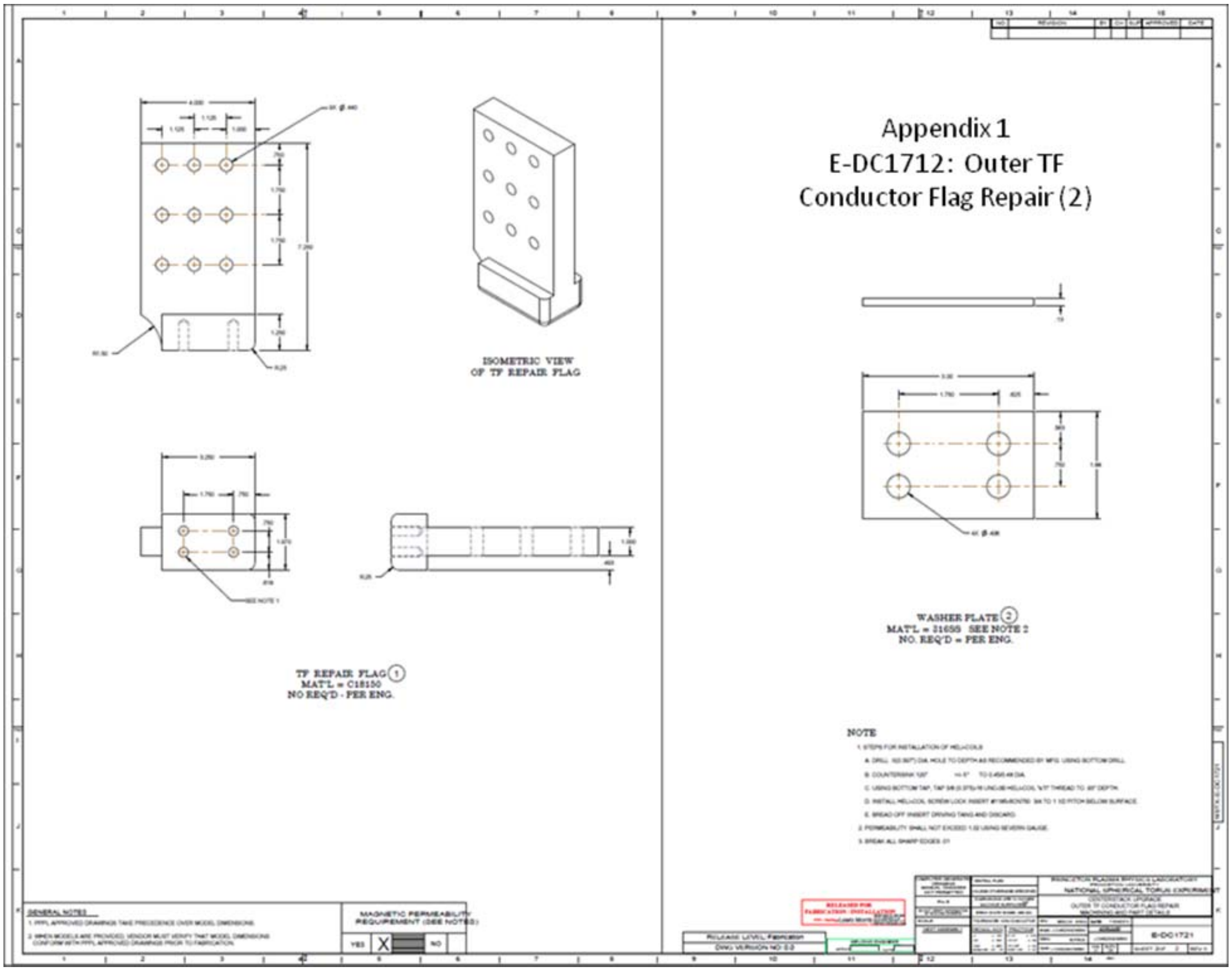
Mike Kalish, Tom Kozub



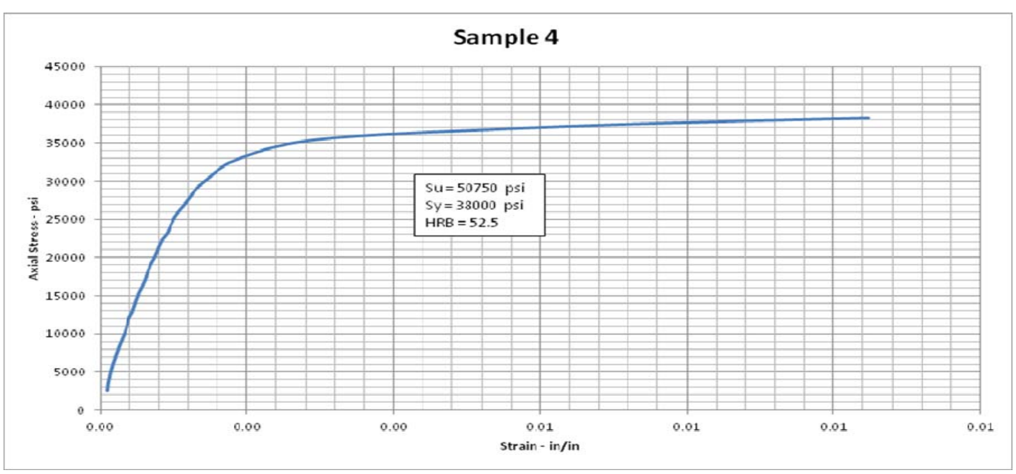




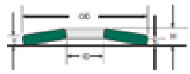
Appendix 1
E-DC1712: Outer TF Conductor Flag Repair (1)



TF Flag Connection Copper Material Test – Stress/Strain Curve Detail



Inconel 718
Belleville Springs

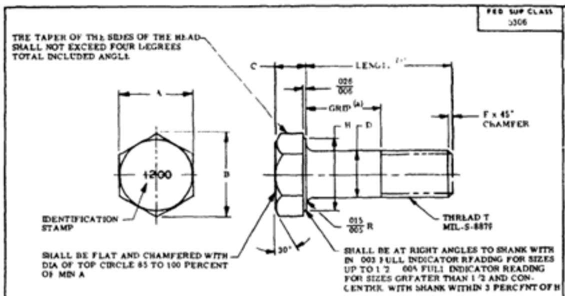


Solon Manufacturing Co.
800-323-9717 • Fax 440-286-9047
e-mail • solon@solonmfg.com

Inconel 718 Nickel Alloy (ASTM B637)
Operating temperature range: - 400° to 1100° F. For high temperature service in corrosive atmospheres. Indoor / outdoor service.
Non-magnetic. Finish: Scale-free and deburred.

Part Number	Bolt Size	ID Min	OD Max	THK (T)	H [a]	DEF (h)	FLAT LOAD	TORQUE [a]
06L21718	#6	0.142	0.281	0.020	0.032	0.005[1]	150	0.4
06M26718	#6	0.142	0.344	0.025	0.040	0.007[1]	230	0.6
06H31718	#6	0.142	0.406	0.030	0.052	0.009[1]	350	0.7
08L26718	#8	0.168	0.344	0.025	0.032	0.006[1]	250	0.7
08M31718	#8	0.168	0.406	0.030	0.045	0.008[1]	370	1.0
010L31718	#10	0.196	0.406	0.030	0.048	0.007[1]	325	1.1
4L42718	1/4	0.258	0.563	0.040	0.064	0.011[1]	615	2.5
4M52718	1/4	0.258	0.688	0.050	0.085	0.015[1]	930	3.9
4H61718	1/4	0.258	0.813	0.061	0.100	0.018	1,300	5.5
51032718	5/16	0.317	0.630	0.030	0.058	0.014[1]	365	1.9
51040718	5/16	0.317	0.630	0.040	0.053	0.012	600	3.1
5L52718	5/16	0.322	0.688	0.050	0.063	0.013	1,000	5.2
5M61718	5/16	0.322	0.813	0.061	0.077	0.016	1,400	7.3
5H70718	5/16	0.322	0.938	0.068	0.090	0.020	1,700	8.9
51680718	5/16	0.322	1.000	0.077	0.101	0.021	2,100	11.3
5EH80718	5/16	0.322	1.063	0.077	0.100	0.023	2,050	10.7
61240718	3/8	0.380	0.755	0.040	0.056	0.016	700	4.4
61261718	3/8	0.380	0.755	0.061	0.073	0.012	1,400	8.8
6L61718	3/8	0.386	0.813	0.061	0.075	0.014	1,200	7.5
6M70718	3/8	0.386	0.938	0.068	0.087	0.019	1,700	12.5
6H80718	3/8	0.386	1.063	0.077	0.101	0.024	2,400	15.0
6EH89718	3/8	0.386	1.188	0.089	0.119	0.026	2,900	18.1
71445718	7/16	0.442	0.880	0.045	0.064	0.019	1,000	7.3

FED SUP CLASS 5306



MS PART NUMBER	THREAD T UNJF-3A	A MAX	A MIN	B REF	C MAX	C MIN	D DIA MAX	D DIA MIN	F MAX	F MIN	H DIA MAX	H DIA MIN
MS20033	0 1900-32	377	365	430	141	109	189	186	047	015	391	359
MS20034	0 2500-28	440	428	510	172	140	249	246	047	015	454	422
MS20035	0 3125-24	502	490	580	204	172	312	309	063	031	516	484
MS20036	0 3750-24	565	553	650	235	203	374	371	063	031	579	547
MS20037	0 4375-20	627	615	720	266	234	437	433	063	031	641	609
MS20038	0 5000-20	752	740	870	297	265	499	495	063	031	766	734
MS20039	0 5625 18	877	865	1 010	328	296	562	558	078	046	891	859
MS20040	0 6250-18	940	928	1 090	360	328	624	620	078	046	954	922
MS20042	0 7500-16	1 066	1 053	1 230	422	390	749	745	078	046	1 079	1 047
MS20044	0 8750-14	1 253	1 240	1 440	485	453	874	869	094	062	1 266	1 234
△ ~~MS20046~~ MS20045	~~1 0000-14~~ 1 0000 12	1 441	1 428	1 660	547	515	999	993	094	062	1 454	1 422

(a) SEE SHEET 2 FOR GRIP AND LENGTH DIMENSIONS. GRIP LENGTH OF BOLTS SHALL BE MEASURED FROM THE UNDERSIDE OF THE HEAD TO THE END OF THE FULL CYLINDRICAL PORTION OF THE SHANK. COMPLETE THREADS SHALL BEGIN WITHIN TWO THREAD PITCH MAXIMUM

△ INACTIVE FOR DESIGN

NOTES
1 MATERIAL. CORROSION AND HEAT RESISTANT STEEL. SEE PROCUREMENT SPECIFICATION
2 GRIP LENGTHS IN ADDITION TO THOSE TABULATED ON SHEET 2 ARE AVAILABLE IN 1/8 INCH INCREMENTS BY THE USE OF SIGNIFICANT DASH NUMBERS. EACH ADDITIONAL WHOLE INCH SHALL HAVE DASH NUMBERS IN UNITS OF TEN WITH DASH 1 TO 7 INDICATING EIGHTHS OF AN INCH. EX. DASH NO 70 = GRIP 7, DASH NO 77 = GRIP 7-7/8
3 EXAMPLE OF PART NUMBER. MS20034-10 = 1/4 INCH DIA BOLT, 1 33/64 INCHES LONG, 1 INCH GRIP
4 BOLTS SHALL BE FREE FROM ALL HANGING BURRS AND SLIVERS WHICH MIGHT BECOME DISLODGED UNDER USAGE
5 DIMENSIONS IN INCHES. UNLESS OTHERWISE SPECIFIED, TOLERANCES ANGLES ±5°
6 UNLESS OTHERWISE SPECIFIED, THREADS IN ACCORDANCE WITH MIL-S-7742 ARE ACCEPTABLE UNTIL 31 DECEMBER 1970
7 FOR INFORMATION MS20500 AND MS20501 NUTS WERE DESIGNED FOR USE WITH THIS BOLT STANDARD

Ⓒ REVISED

APPROVED 29 FEB 52 REVISED Ⓐ 4 Dec 1968 Ⓑ 13 JULY 1969 Ⓒ 11 June 1970

P.A. NAVY - AS; Other Cust: ARMY - MU, USAF - 82	TITLE: BOLT, MACHINE, HEXAGON HEAD, 1200 F	MILITARY STANDARD MS20033 THRU 20046
PROCUREMENT SPECIFICATION: MIL-B-7874	SUPERSEDES: MS20033-MS20046 INCLUSIVE (AS)	SHEET 1 OF 2

DD FORM 672-1

FED SUP CLASS 5306

DASH NO	GRIP ±1/64	LENGTH, +1/32 -1/64 MS20033	MS20034	MS20035	MS20036	MS20037	MS20038	MS20039	MS20040	MS20042	MS20044	MS20045 MS20046
1	1/8	35/64	41/64	11/16	51/64	13/16	61/64	1-1/16	1-1/8	1-1/4	1-13/32	1-17/32
2	1/4	43/64	49/64	13/16	59/64	15/16	1-5/64	1-3/16	1-1/4	1-3/8	1-17/32	1-21/32
3	3/8	51/64	57/64	15/16	1-3/64	1-1/16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	1/2	59/64	1-1/64	1-1/16	1-11/64	1-3/16	1-21/64	1-7/16	1-1/2	1-5/8	1-25/32	1-29/32
5	5/8	1-3/64	1-9/64	1-3/16	1-19/64	1-5/16	1-29/64	1-9/16	1-5/8	1-3/4	1-29/32	2-1/32
6	3/4	1-11/64	1-17/64	1-5/16	1-27/64	1-7/16	1-37/64	1-11/16	1-3/4	1-7/8	2-1/32	2-5/32
7	7/8	1-19/64	1-25/64	1-7/16	1-35/64	1-9/16	1-45/64	1-13/16	1-7/8	2	2-5/32	2-9/32
10	1	1-27/64	1-33/64	1-9/16	1-43/64	1-11/16	1-53/64	1-15/16	2	2-1/8	2-9/32	2-13/32
11	1-1/8	1-35/64	1-41/64	1-11/16	1-51/64	1-13/16	1-61/64	2-1/16	2-1/8	2-1/4	2-13/32	2-17/32
12	1-1/4	1-43/64	1-49/64	1-13/16	1-59/64	1-15/16	2-5/64	2-3/16	2-1/4	2-3/8	2-17/32	2-21/32
13	1-3/8	1-51/64	1-57/64	1-15/16	2-3/64	2-1/16	2-13/64	2-5/16	2-3/8	2-1/2	2-21/32	2-25/32
14	1-1/2	1-59/64	2-1/64	2-1/16	2-11/64	2-3/16	2-21/64	2-7/16	2-1/2	2-5/8	2-25/32	2-29/32
15	1-5/8	2-3/64	2-9/64	2-3/16	2-19/64	2-5/16	2-29/64	2-9/16	2-5/8	2-3/4	2-29/32	3-1/32
16	1-3/4	2-11/64	2-17/64	2-5/16	2-27/64	2-7/16	2-37/64	2-11/16	2-3/4	2-7/8	3-1/32	3-5/32
17	1-7/8	2-19/64	2-25/64	2-7/16	2-35/64	2-9/16	2-45/64	2-13/16	2-7/8	3	3-5/32	3-9/32
20	2	2-27/64	2-33/64	2-9/16	2-43/64	2-11/16	2-53/64	2-15/16	3	3-1/8	3-9/32	3-13/32
21	2-1/8	2-35/64	2-41/64	2-11/16	2-51/64	2-13/16	2-61/64	3-1/16	3-1/8	3-1/4	3-13/32	3-17/32
22	2-1/4	2-43/64	2-49/64	2-13/16	2-59/64	2-15/16	3-5/64	3-3/16	3-1/4	3-3/8	3-17/32	3-21/32
23	2-3/8	2-51/64	2-57/64	2-15/16	3-3/64	3-1/16	3-13/64	3-5/16	3-3/8	3-1/2	3-21/32	3-25/32
24	2-1/2	2-59/64	3-1/64	3-1/16	3-11/64	3-3/16	3-21/64	3-7/16	3-1/2	3-5/8	3-25/32	3-29/32
25	2-5/8	3-3/64	3-9/64	3-3/16	3-19/64	3-5/16	3-29/64	3-9/16	3-5/8	3-3/4	3-29/32	4-1/32
26	2-3/4	3-11/64	3-17/64	3-5/16	3-27/64	3-7/16	3-37/64	3-11/16	3-3/4	3-7/8	4-1/32	4-5/32
27	2-7/8	3-19/64	3-25/64	3-7/16	3-35/64	3-9/16	3-45/64	3-13/16	3-7/8	4	4-5/32	4-9/32
30	3	3-27/64	3-33/64	3-9/16	3-43/64	3-11/16	3-53/64	3-15/16	4	4-1/8	4-9/32	4-13/32
31	3-1/8	3-35/64	3-41/64	3-11/16	3-51/64	3-13/16	3-61/64	4-1/16	4-1/8	4-1/4	4-13/32	4-17/32
32	3-1/4	3-43/64	3-49/64	3-13/16	3-59/64	3-15/16	4-5/64	4-3/16	4-1/4	4-3/8	4-17/32	4-21/32
33	3-3/8	3-51/64	3-57/64	3-15/16	4-3/64	4-1/16	4-13/64	4-5/16	4-3/8	4-1/2	4-21/32	4-25/32
34	3-1/2	3-59/64	4-1/64	4-1/16	4-11/64	4-3/16	4-21/64	4-7/16	4-1/2	4-5/8	4-25/32	4-29/32
35	3-5/8	4-3/64	4-9/64	4-3/16	4-19/64	4-5/16	4-29/64	4-9/16	4-5/8	4-3/4	4-29/32	5-1/32
36	3-3/4	4-11/64	4-17/64	4-5/16	4-27/64	4-7/16	4-37/64	4-11/16	4-3/4	4-7/8	5-1/32	5-5/32
37	3-7/8	4-19/64	4-25/64	4-7/16	4-35/64	4-9/16	4-45/64	4-13/16	4-7/8	5	5-5/32	5-9/32
40	4	4-27/64	4-33/64	4-9/16	4-43/64	4-11/16	4-53/64	4-15/16	5	5-1/8	5-9/32	5-13/32
41	4-1/8	4-35/64	4-41/64	4-11/16	4-51/64	4-13/16	4-61/64	5-1/16	5-1/8	5-1/4	5-13/32	5-17/32
42	4-1/4	4-43/64	4-49/64	4-13/16	4-59/64	4-15/16	5-5/64	5-3/16	5-1/4	5-3/8	5-17/32	5-21/32
43	4-3/8	4-51/64	4-57/64	4-15/16	5-3/64	5-1/16	5-13/64	5-5/16	5-3/8	5-1/2	5-21/32	5-25/32
44	4-1/2	4-59/64	5-1/64	5-1/16	5-11/64	5-3/16	5-21/64	5-7/16	5-1/2	5-5/8	5-25/32	5-29/32
45	4-5/8	5-3/64	5-9/64	5-3/16	5-19/64	5-5/16	5-29/64	5-9/16	5-5/8	5-3/4	5-29/32	6-1/32
46	4-3/4	5-11/64	5-17/64	5-5/16	5-27/64	5-7/16	5-37/64	5-11/16	5-3/4	5-7/8	6-1/32	6-5/32
47	4-7/8	5-19/64	5-25/64	5-7/16	5-35/64	5-9/16	5-45/64	5-13/16	5-7/8	6	6-5/32	6-9/32
50	5	5-27/64	5-33/64	5-9/16	5-43/64	5-11/16	5-53/64	5-15/16	6	6-1/8	6-9/32	6-13/32

BOLT STRENGTH REQUIREMENTS IN POUNDS LOAD

BOLT SIZE	TENSILE BREAKING STRENGTH, MINIMUM: ROOM TEMPERATURE	TENSILE BREAKING STRENGTH, MINIMUM: 23 HOURS 1,200°F RUPTURE	DOUBLE SHEAR STRENGTH MINIMUM ROOM TEMPERATURE
10	3 000	1 100	4 700
1/4	5 400	2 100	8 300
5/16	8 600	3 400	13 000
3/8	13 300	5 300	18 800
7/16	18 000	7 100	25 600
1/2	24 000	9 700	33 400
9/16	30 500	12 300	42 200
5/8	38 100	15 600	52 200
3/4	55 300	22 800	75 100
7/8	75 500	31 200	102 000
1	98 400	42 000	133 500

NOTE: TENSILE AND RUPTURE STRENGTH FIGURES GIVEN IN THE ABOVE TABLE ARE FOR MINIMUM VALUES ONLY AND ARE CALCULATED FROM THE MEDIAN (MEAN BETWEEN BASIC PITCH AND BASIC ROOT DIAMETERS) AREA OF THE THREAD. MAXIMUM VALUES WILL NOT BE CAUSE FOR REJECTION, PROVIDED BOLTS SHOW SATISFACTORY DUCTILITY AS MEASURED BY THE BEND TEST. SHEAR STRENGTH FIGURES ARE CALCULATED ON THE BASIS OF 60 PERCENT OF THE TENSILE STRENGTH OF THE MATERIAL AT THE MINIMUM SHANK DIAMETER.

APPROVED 29 FEB 52 REVISED Ⓒ FOR CHANGES SEE SHEET 1

P.A. NAVY - AS; Other Cust: ARMY - MU, USAF - 82	TITLE: BOLT, MACHINE, HEXAGON HEAD, 1200°F	MILITARY STANDARD MS20033 THRU 20046
PROCUREMENT SPECIFICATION: MIL-B-7874	SUPERSEDES: MS20033-MS20046 INCLUSIVE (AS)	SHEET 2

DD FORM 672-1